Introduction

The intent of this paper is to review the different sensor technologies that are in use today for the measurement of water vapor content in natural gas. It will also address key issues and proper procedures in assembling a sample delivery system to provide a clean, representative gas sample to the sensing device. Natural gas is one of the most widely used fuels today for everything from home heating to power generation, and maintaining the gas quality is of great concern. The determination of the water vapor content in natural gas is one of several key factors used to determine the ultimate quality of the gas. With economic conditions as they exist today, many companies have been forced to cut personnel in order to maintain a reasonable balance sheet. The loss of experienced measurement technicians places a heavy burden on instrument manufacturers to provide an accurate and reliable means of making this measurement.

Impact of Water Vapor on Gas Quality

As removed from the ground, natural gas is typically described as being either rich or lean (wet or dry) as relates to the heavier hydrocarbon components in the gas stream. In addition to these hydrocarbons, natural gas will almost always contain water vapor as well as nitrogen, helium, carbon dioxide and, in some cases, hydrogen sulfide. Our focus here will be on one of the most undesirable components, water, both as free water and water vapor.

Natural gas, as removed from the ground, can be saturated with water vapor and must go through a dehydration process prior to transportation in the vast network of underground transmission pipelines. The dehydration process can be accomplished through various means. The most typical dehydration technique is to pass the gas through a TEG (tri-ethylene glycol) contactor or diverting the gas through a molecular sieve desiccant bed. Both of these processes will add up front cost to the gas, but are necessary for the following reasons:

1. Water vapor can combine with other trace contaminants in the gas stream, namely H$_2$S and CO$_2$, and form potentially corrosive acids in the pipeline. The presence of these acids in the pipeline will decrease the life expectancy of the pipeline and its components. Long-term maintenance costs will increase as will the potential for catastrophic failure of the pipeline or any one of its components.

2. Rapid expansion of the high pressure natural gas will cool the gas based on the Joules Thompson effect. For every 100 psig drop in pressure, there can be a 6 or 7 degree drop in temperature. The interaction of water vapor with heavier hydrocarbons in the gas stream at this point can result in the formation of hydrates. These hydrates can cause complete or partial blockage in valves, regulators or measurement devices in the pipeline resulting in significant downtime while the hydrate is thawed or removed from the pipeline.

3. Contractual obligations at custody transfer points require that the gas not exceed a specified maximum moisture level. Typical contracts call for this maximum to be 7 lbs/mm$^3$cf, although this number may change depending upon the geographic area and normal ambient conditions.

4. The BTU or heating value of the gas will be reduced as the amount of water vapor increases. If contractual obligations are not met, the producer can be shut in and will face a loss of revenue until the problems are corrected.

Sensor Technologies

Today, there are many manufacturers of moisture analyzers and sensors competing for a slice of the sales pie. Most of these manufacturers will use a sensor that falls into one of the five basic technologies used to determine the water vapor content of the gas. They are:

1. Electrolytic
2. Capacitance
3. Chilled Mirror
4. Vibrating Crystal
5. Laser Spectroscopy

In addition to these types of sensors, length of stain tubes are also widely used as a rough guide to determine an approximate water vapor content.
Absolute vs. Relative

All sensor types will fall into one of two categories – Absolute or Relative measurement. Absolute sensors are based on primary laws of physics and do not require periodic calibration against known moisture standards, nor can the sensors actually be calibrated. Relative sensors are based on a comparative measurement and will require a known, certified moisture source for calibration. Calibration frequency will vary depending on the individual sensor characteristics.

Electrolytic Sensors

Electrolytic sensors are unique in that they can be either absolute or relative measurement devices. In either case, the basic operation of the sensor is the same.

The typical electrolytic sensor consists of two precious metal electrodes, wound around a support mandrel or imbedded in a hollow glass tube. These electrodes are then coated with a thin layer of phosphorus pentoxide \((P_2O_5)\). In operation, a controlled amount of gas is allowed to constantly flow through or across the sensor allowing sufficient time for the \(P_2O_5\) coating to adsorb all of the moisture from the gas stream. A voltage potential is applied across the electrodes, splitting (electrolyzing) the water molecules that have been collected on the coating. Once equilibrium conditions are attained, the rate at which moisture molecules enter the cell will exactly match the rate at which the molecules are electrolyzed. Each electrolyzed molecule causes two electrons to be displaced from the anode to the cathode. The electrolysis current (Amps) gives the electrical charge (coulombs) discharged per second. Since the elementary charge of an electron is known, by measuring the current we can determine the rate at which water molecules are entering the sensor. Combined with a known flow rate through the sensor, the moisture content of the gas can be determined. The critical aspect here is the controlled flow rate, as this is the lone variable in the absolute measurement version of electrolytic based analyzers.

Electrolytic sensor based moisture analyzers are available as portable and stationary devices with flow control mechanisms built into the unit. As with all analyzers, it is important that the proper sampling techniques and sample conditioning criteria be strictly adhered to. Failure to do so may cause premature failure of the sensor. Liquid intrusion or the presence of conductive particles will also cause premature sensor failure.

Chilled Mirror

Commonly known as the Bureau of Mines Tester, the chilled mirror hygrometer is a very simple and basic moisture measurement device that has been used for many years as a primary, absolute moisture measurement tool. In operation, the sample gas stream flows across a temperature controlled polished surface or “mirror”. As the temperature of the mirror is slowly lowered, the water vapor will begin to condense or form dew on the mirror. The temperature at which the dew first appears is considered the dew point. Once the temperature dew point is attained, a simple conversion using existing charts or tables will provide the actual water vapor content of the gas. This type of analyzer can also be utilized to determine hydrocarbon dew points in the gas stream. Usually, an iridescent ring will form on the mirror surface indicating you have reached the hydrocarbon dew point temperature. Moisture dew point will appear as a cloudy, opaque spot in the center of the mirror.

The critical components of the chilled mirror analyzer are the pressure chamber with valves to control the gas flow and pressure, a small mirror or polished surface, a thermometer or thermocouple to measure the mirror temperature, a chilling device (typically propane or \(CO_2\)) and a view port to allow for observation of the mirror. In applications where the ambient temperature is below the dew point of the gas, it may be necessary to heat the sample line and analyzer to prevent condensation in the sampling system. Care should also be taken so as not to confuse dew point with frost point. Significant errors can occur when converting dew/frost point values to actual moisture content (i.e. a reported dewpoint of \(-40\,^\circ C\) at atmospheric pressure is equivalent to \(8.8\, \text{lbs/mmscf}\) while the same frost point temperature translates to \(6\, \text{lbs/mmscf}\)).

Since this is a direct measurement device, no calibration of the system against a known moisture standard is required. Care should be taken to collect a representative sample of the gas using proper sampling and filtration techniques. Experienced operators can make highly accurate and reproducible measurements, but inexperienced operators may have some problems associated with interpreting the visual results. It is not uncommon to get different results from different operators on the same gas line.

Capacitance Sensors

Capacitance sensors fall into the category of relative measurement devices. Periodic calibration of the sensor against a known moisture standard is an absolute requirement. Of all the different sensor
technologies, capacitance sensors are the choice of a majority of manufacturers. There are numerous types of capacitance sensors, including aluminum oxide, silicon oxide, polymer base and thin film, but they all share the same basic principle. Regardless of the sensor type, the core of the sensor consists of two electrodes and a dielectric material that absorbs the water vapor in the gas stream and achieves an equilibrium condition based on the partial pressure of water vapor in the specific gas stream.

In operation, moisture in the sample stream is absorbed into the dielectric material creating impedance within the sensor. An excitation voltage is applied to the electrodes and a return signal, proportional to the water vapor content, is transmitted back to the base electronics.

Capacitance sensor based analyzers are available in both portable and stationary configurations. Although the sensor probe can be mounted directly in the process line, glycol and other contaminants in the gas stream can cause false readings and premature sensor failure. The sensor should be mounted in an independent sample conditioning system adjacent to the sample point in order to protect against sensor contamination and to facilitate calibration and maintenance.

Vibrating Crystal Sensors

Piezo-Electric sensors are commonly referred to as vibrating quartz crystal sensors. The crystal is coated with a hygroscopic material in order to allow absorption of the water vapor from the gas stream. The analyzer electronics monitor the vibration frequency change of the crystal as water vapor is absorbed onto the coating. During operation, the crystal is alternately exposed to the sample gas stream and a dry reference stream. The reference stream is the actual sample gas, passed through an on-board gas dryer.

In operation, the sample gas flows across the crystal for a fixed time period. During this time, moisture in the gas stream is absorbed onto the coating of the crystal causing a change in the vibration frequency. This frequency is read, stored and compared against a sealed crystal. The sample gas is then diverted through the on board dryer and again is passed across the crystal. Once again, the frequency is read, stored and compared against the sealed crystal. Using the differential in the vibration frequency of the sample gas and the dried sample gas, one can determine the water vapor content of the sample gas.

These analyzers are strictly stationary devices and are not suitable for portable applications. They are also considered relative measurement devices that require periodic calibration against a known moisture source. It is common to have a moisture generator built into the analyzer to simplify the calibration process.

Laser Spectroscopy Analyzers

Laser based analyzers are the new wave of moisture measurement technology. The basic principle is rather simple. Every molecule has a unique electronic signature or “fingerprint”. By tuning a laser beam to a specific wavelength and passing it through the sample cell, the light energy will be absorbed by the molecules in the gas stream that have an electronic signature at the selected wavelength. The absorption of the laser energy is directly related to the concentration of the selected molecule. The advantage of a laser is the ability to detect different molecules, assuming there is a laser diode available within the absorption wavelength for the specific molecule. Currently available systems are capable of detecting moisture and carbon dioxide with individual, dedicated laser diodes and sample chambers.

The basic concept is simple, but the reality is less so. Even though every molecule has a unique fingerprint, other molecules may have a lesser absorption efficiency at the same wavelength, leading to false values. It is critical to select a wavelength where no other molecule within your specific sample stream can also absorb the light energy. Not all applications are suitable for laser based systems.

One of the key advantages of laser based measurement is that the sensor itself is not in direct contact with the gas sample. This avoids the traditional problem of sensor contamination, but does not preclude the need for proper sample conditioning. The critical component in all laser spectroscopy systems is the mirror. Any deposits on the mirror surface can adversely affect the reflectivity of the mirror, which, in turn, will lead to a loss in sensitivity.

Stain Tubes

For those of us who might only be interested in ballpark numbers on an infrequent basis, the length of stain tubes may be the best alternative. Encased in a glass tube, a chemically treated compound will change color when exposed to moisture in the sample gas. This is a quick and rough method to get a visual indication of the moisture content of the gas stream. Accuracy of these tubes is only ± 25% and is dependent upon the operator. Sampling is accomplished by breaking off both ends of the glass
tube and inserting it into a hand pump. Care must be taken to avoid contaminating the reading with atmospheric moisture. A fixed number of pump strokes is required to achieve the final moisture value.

Although this technology is not suited for custody transfer measurements, it is a useful tool when looking for a quick, rough measurement. If you suspect high moisture content at your sample point, use the stain tube as the first pass before exposing the sensitive analyzer to potentially high water content gas. Moisture analyzers do like to be hit with saturated gas and are traditionally slow to respond after being saturated with water vapor. Stain tubes are quick, one time use devices that are not bothered by saturated gas.

**Sampling Systems**

All of these sensing technologies have their own advantages and shortcomings, but one issue is never in doubt. That is to say, we must use proper sampling techniques and sample conditioning to bring a representative gas sample to the sensing element.

The design of the sampling system should adhere to some basic principles. These principles include the following:

1. Use high quality stainless steel components
2. Low volume components
3. Avoid dead space
4. Use a sample probe
5. Install and maintain proper filters

The first and most important component of the sampling system is the sample probe. The sample probe should be installed in the pipeline such that you are extracting gas from the center third of the flowing gas stream. The reason for this is to avoid pulling all of the collected liquids off the walls of the pipe and putting them directly into your analyzer. What we are trying to do is to sample the gas phase, not the liquid phase.

Probably the single largest cause of failure of a moisture sensor is contamination. Although the sample probe is critical, this does not eliminate the need for additional filtration. There is always the potential for entrained liquids in the sample stream and these liquids must be removed. These liquids include glycol, methanol, hydrocarbon liquids and compressor oil to name a just a few. It is imperative that a filtration system be installed upstream of your analyzer. Ideally, any sample conditioning should be designed specifically for the individual application, but most sample systems will consist of a liquid removal filter along with a glycol or oil vapor removal filter. Liquid removal can be accomplished with a coalescing filter or a membrane separator or a combination of both. Glycol vapor filters are also available in a variety of sizes and configurations. I suggest discussing your application with the analyzer supplier to determine to what extent you will need filtration. Also remember that filters require periodic maintenance. Don’t install a system and forget about it, rather, maintain it according to the supplier’s guidelines.

Several other points to consider in the sampling system are:

1. Always use stainless steel sample lines and components to minimize corrosive effects and to maintain good sensor performance. Too many times, the inclination is to use any old rubber hose that happens to be lying around to deliver the sample to the analyzer and then blame the analyzer when the readings are not correct.
2. Select a sample point that is free from swirling gas flow. Try to select a sample point that is in the middle of straight, unimpeded run of pipe. Elbows, orifice plates and control valves can create swirl effects, which can sweep liquids from the wall of the pipe and right into the analyzer.
3. Design your sample system with minimal dead volume components to help the analyzer respond quickly to changes in moisture. Keep the components to an absolute minimum and place your analyzer as close as possible to the sample point. The more complex your sampling system is, the more time it will take to both purge it out and get a representative gas sample to your analyzer.

Using these basic guidelines, you can design a system that will give you protection from contamination while at the same time bringing a representative gas sample to your analyzer.

**Conclusion**

There are a variety of sensor technologies in use today and the choice ultimately lies with the end user. All devices have their own advantages and disadvantages, but one thing is certain, if you don’t provide a clean, representative gas sample to the sensor, you will have difficulty in making an accurate determination of the water vapor content of your gas stream.