Technology Document
Version 2.1.0
For the DMC 300 Series

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1. Introduction

Continuous moisture measurement in gas flows at elevated temperatures has always presented a challenge for real-time control. High levels of particulate and reactive compounds have also prevented accurate and reliable measurement.

The H2O Moisture Measurement Technology overcomes the barriers by making a direct physical measurement of water molecules utilizing a "dipole polarization" effect.

Some of the important features of the $H2O$ **Technology are:**
- Can measure the complete range of moisture content - from zero to saturation.
- In-situ use to 851°F (455°C) with no sampling or preparation.
  Sampling systems also available.
- An effective filtering system permitting long maintenance free intervals even in strongly polluted measuring atmospheres.
- Simple; one-step installation for standard models.
- Inert measuring probe - unaffected by reactive gases.
- Very quick response.
- No recalibration if system is undamaged.

2. Background

The Measurement Technology was developed out of the need for a moisture sensor to successfully operate in high temperature, particulate laden, reactive gas environments. Conventional moisture measurement techniques utilize a derived property of water such as capacitance, conductance, infrared absorption etc.

The H2O Technology "directly" measures the number of water molecules to provide a % volume or absolute humidity value. The units of measurement of moisture content vary with each sensor manufacturer and application (absolute humidity, % volume, dew point, wet/dry temperatures, relative humidity, PPM, specific humidity, mass ratio etc.) and are often reliant on accurate pressure and temperature data. Thus, a process engineer may specify mass ratio, requiring pressure and temperature measurement, when % volume or absolute humidity may very well suffice.

Process moisture measurement has to take into account six factors that may prevent a sensor from being accurate and reliable:

1. Sampling : Extracting a "representative" sample from a process stream involve filters, valves, pumps, relays etc. which can prove quite difficult at elevated temperatures and high particulate loading. Maintenance on complicated sampling mechanisms can also be expensive and time consuming.

2. Temperature : Higher temperatures usually degrade the accuracy of any sensor (Wet/dry bulb measurements cannot be made above 100°C). Sensors using polymers, salts, gels and strains are more susceptible than others. Cyclic temperature variation in a process may inflict additional damage to sensors. Many moisture sensors incorporate an electronic circuit that amplifies the low amplitude signal from the sensor to a usable level. The electronics are usually placed close to the sensor to avoid signal losses. Placing the sensors in high temperatures degrades the electronics over a period of time and causes signal drift.

3. Particulate : Particulate is a major problem in all in-situ sensors. It is especially difficult when the particles are of varied sizes and hygroscopic. Sintered frits made of steel or ceramic are commonly employed in various thickness and configurations to exclude particles from the environment around the sensor. Variable particle sizes cause the pores in the frits (usually 1 - 10 microns) to be clogged fairly quickly. Moisture molecules cannot be transported through the congested pores and the sensor fails to respond - usually generating a constant signal corresponding to the moisture in the environment in the immediate vicinity of the sensor. Hygroscopic particulate exacerbates the situation by forming a paste and sealing pores in the frit or filter in the presence of condensed moisture.

4. Calibration : Conventional moisture sensors have to be calibrated -- involving salt solutions or complicated optics. The act of calibration prevents continuous operation in most in-situ instruments. Manual calibration is susceptible to various errors and the traceability is limited.

5. Interference : Compounds in process flows often interfere with conventional moisture sensors. Molecules that act as dielectric (or conductors of electrons) cause errors in moisture sensors utilizing capacitance and electrical impedance techniques. Most conventional sensors have low specificity to moisture and thus may require frequent calibration in the presence of interferents.

6. Corrosion : Varying pH levels, presence of acid gases and other reactive molecules, even in small quantities, can quickly corrode sensors and probes. Corrosion due to moisture condensation is often a cause of failure. A combination of particulate buildup, moisture levels and condensation increases the corrosion rate.

H2O Moisture Analyzers are designed to successfully address the above factors to provide an accurate and reliable moisture measurement.

3. The Measurement Principle

Water molecules are formed by special covalent bonds between oxygen and hydrogen atoms. Each electron is shared unequally between the oxygen and hydrogen atoms - more by the oxygen. This unequal sharing creates an electrical asymmetry, forming a dipole molecule (Fig. 1). Each water molecule thus has two slightly positive-charged hydrogen atoms and a slightly negative-charged oxygen atom.

Water molecules in an electrically charged chamber will tend to align with the electric field because of their dipole nature. The degree of alignment depends on the forces of thermal disorder (inversely proportional to temperature) and the strength of the electric field [2].
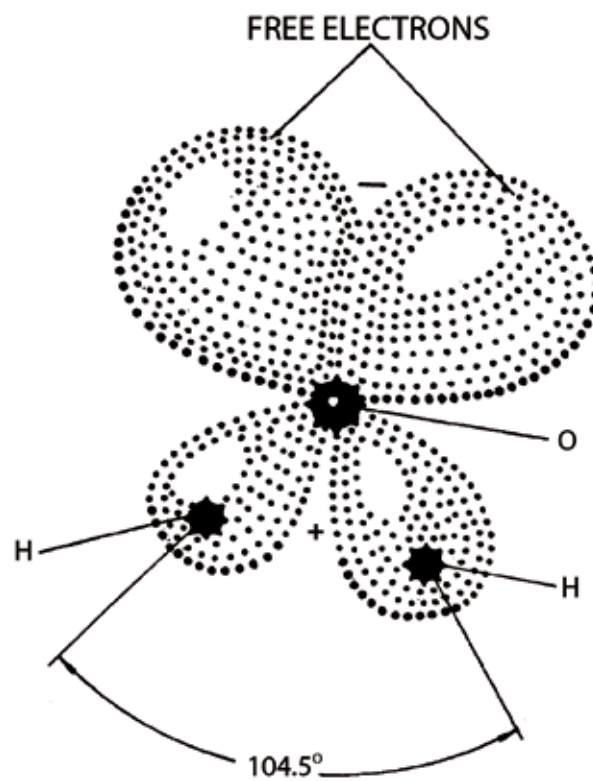

FIG. 1 - STRUCTURE OF WATER MOLECULE

4. Description of the Analyzer System

The energy consumed to align the water molecules can be calculated from the forces of disorder which are temperature and the number of polar molecules in the electric field. Therefore, it is possible to obtain the number of polar molecules in the field at a known temperature. This is accomplished by measuring the consumption of electrical energy in the field utilizing a very sensitive current measurement. This is the "measuring effect" of the analyzer.

Unfortunately, dipole polarization is not the only electrical effect in the chamber, especially if that chamber is open to process atmosphere. The much stronger effect of "ion" or surface polarization is always present if there are small traces of ionic material (such as dust). As ion polarization relates to the "movement" of molecules, it is much slower than the "alignment" of polar molecules in dipole polarization. By providing a cyclic electrical field around the chamber and choosing a field frequency above 10 kHz, the influence of ion polarization can be sufficiently reduced. In the H2O analyzer, the sensor chamber field is operated at 20 kHz, where the circuits are sufficiently stable considering the present state-of-the-art analog electronics.

Interference from other polar molecules is negligible because water is unique in that, molecular mass is very small and the dipole momentum very high. This results in a two-fold advantage -- since the measurement effect is sensitive to the number of molecules, a polar molecule with a large molecular mass has a lower molecule count at the same mass concentration when compared to water. Secondly, the larger molecular mass suppresses its tendency of dipole alignment at 20 kHz.

4.1 Sensor

The sensor is a chamber which forms an open capacitor whose dielectric varies with the process environment. The moisture in the form of vapor diffuses through a membrane filter (described later) into the capacitor.

As discussed earlier, the "measuring effect" is precisely proportional to the number of water molecules present in the measuring capacitor at any instant. The volume of the chamber is fixed by design. Thus the measuring effect is a direct linear component of the unit of weight per unit of volume - deriving a mass/unit volume output. The measuring unit is gm/m3.

The challenge in this measurement concept is the relative order of magnitude of the measuring effect and the capacitance of the empty (in a vacuum) chamber. The capacitance of the empty sensor chamber is 0.5pF. In trace levels (parts per million) of moisture, the change in capacitance is on the order of only 10-5pF. Since the chamber is exposed to high temperature process environments, it prevents the placement of electrical amplifiers in the immediate vicinity.

The analyzer design includes auxiliary fields to shield side effect interferences. The design also includes high precision machining of the measurement chamber and support assemblies while incorporating a highly integrated analog amplification circuit inside the transmitter housing.

Linearization and mathematical correction of the sensor signal is not needed due to the direct physical measurement principle.

4.2 Probe

The probe encloses the sensor chamber that is placed behind a membrane filter. The probe is cylindrical, 86.9mm in diameter and 490 mm long. Fig. 3 shows a simplified schematic of the probe cross-section.
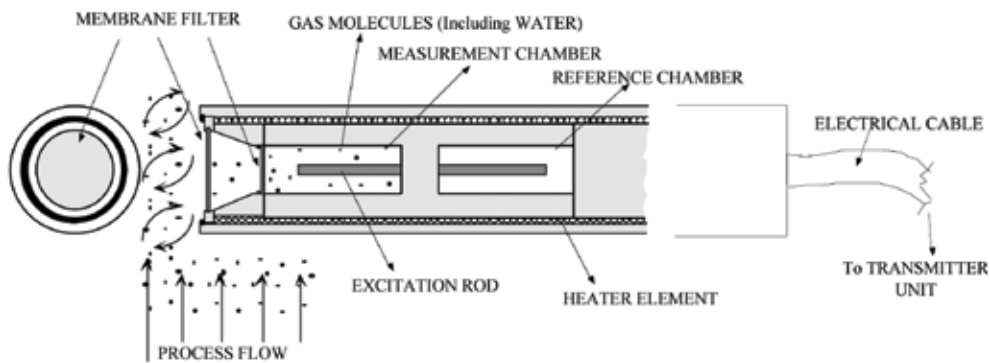

FIG. 3 - PROBE SCHEMATIC

The standard probe is constructed from stainless steel but can also be made from Inconel for extremely corrosive environments.

The probe is internally heated to a fixed temperature where the value is determined by the specific application. The heated probe enables the moisture measurement to be made at a constant temperature and minimizes corrosion of the probe components due to moisture condensation. Additionally, particulate build-up is reduced on a heated probe in certain applications.

For steady processes, the probe temperature is set 10° above process temperature. Cyclical process with long periods at various temperature levels, require the probe temperature to be set 20° to 50° above the maximum process temperature. The heated portion of the probe that is inserted into the process is constructed entirely from metal and ceramic components - the maximum temperature is limited only by the integrity of the material at high temperatures. Versions of the probe have been used to measure moisture in temperatures as high as 450°C (851°F).

4.3 Membrane Filter

The membrane filters for high temperature processes are constructed from Al2O3 (Aluminum Oxide). Unique construction of the filter allows it to approach the truly ideal filter medium - a surface filter. An ideal surface filter has no thickness, has pores that are openings in the two-dimensional surface, and has a high percentage of the surface area occupied by the pores.
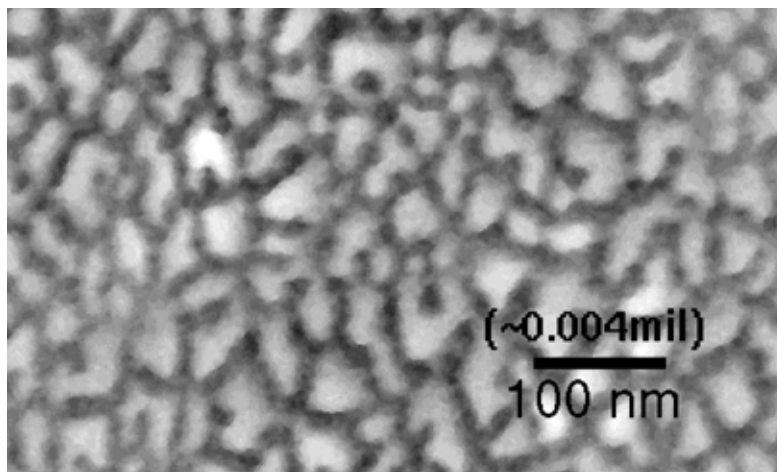

FIG. 4 - ELECTRON MICROSCOPE MAGNIFIED SURFACE OF MEMBRANE FILTER

The membrane material is manufactured such that crystalline structures form a honeycomb-like structure. An electron microscope photograph of the filter material (Fig. 4), shows the pores (represented by white areas bounded by dark structures) ranging in size from 50 nanometers (50 x 10-9 meters) to 100 nanometers. The filter membrane is mounted permanently on a metallic support disk, which in turn is mounted at the very tip of the probe. The nanometer sized pores effectively prevent particulate (usually micron sized) from entering the probe while allowing gas molecules (including water vapor) to diffuse through to the sensor chamber behind the filter.

Particulate build-up on the filter is prevented by utilizing the dynamics of the process flow and the flexibility of the membrane. Typically, process gases flow over the tip of the cylindrical probe as shown in Fig. 3. Fluid dynamics will cause turbulence to occur at the tip, resulting in varying levels of pressure on the filter in a continuous manner. These pressure forces cause the flexible filter membrane to rapidly vibrate - effectively knocking off particulate. Additionally, since the probe (and hence the filter) is heated to a temperature above the condensation temperature of moisture in the process conditions, the particulate is easily dislodged from the probe.

4.4 Electronics

The schematic of the electrical circuit of the instrument is shown in Fig. 5. The sensor is made of a capacitive half bridge formed from two coaxial capacitors. One capacitor is open to the measuring atmosphere while the other is hermetically sealed. The dielectric of the first is formed by the sample being measured and the second forms a constant reference capacitor. The capacitive half bridge is excited with a sine wave from an alternating signal. A second half bridge placed in the transmitter unit is connected to the probe-based half bridge to form a full bridge. The zero-signal tap of the two bridges are led to a two-channel AC amplifier which amplifies the signal from about 0.5mVpp to about 20 Vpp.

These two signals are rectified, compared, and the corresponding DC voltage of the moisture content is filtered out. 1000 gm/m3 corresponds to about 1 mV. The signal is further amplified in a single channel amplifier so that a 0 - 10 V DC range corresponds to the desired measuring range. Finally, from this signal a 4 ... 20 mA DC signal is derived via a current interface circuit. The measurement and reference capacitors are manufactured dimensionally the same and are arranged sequentially in the probe tip so they are always subject to the same temperature. This provides a stable capacitor arrangement whose errors are small compared to the measurement signal.
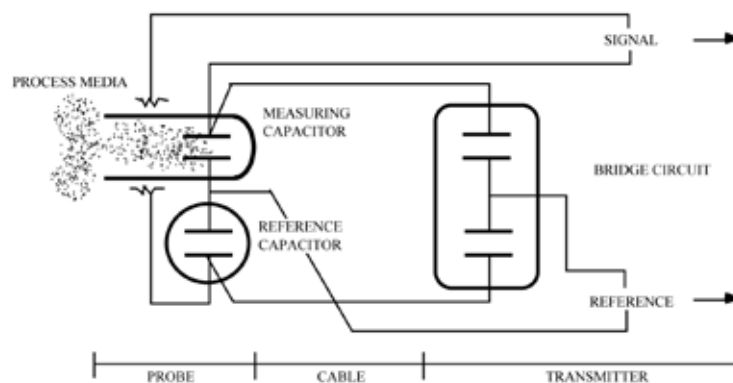

FIG. 5 - ELECTRICAL SCHEMATIC

Errors due to amplification are offset since the zero point reference capacitor is subject to the same error as the entire measurement chain. This is because the zero point of an analytical instrument is very easy to calibrate whereas the amplification factor can only be calibrated with difficulty.

5. Calibration

As is evident from the principle of measurement, the measured signal is directly proportional to the number of water molecules. A constant zero reference is provided by the hermetically sealed capacitor provided in the probe. Thus, once the zero reference is established, only one other point of calibration is necessary for the entire range (0-100% volume).

The calibration will not change for the life of the instrument as long as the physical integrity of the measuring and the reference chambers are maintained. The minute nature of the measuring effect ensures that any change in the integrity of the probe results in an off-scale reading. This is a comprehensive indication of the failure of the calibration and the instrument.

The initial calibration is done after the manufacture of the probe. The probe is first subjected to a 4 week aging cycle (rapid temperature changes from room to 200°C every hour). Every 12 hours an additional calibration cycle is carried out with steam at 200°C. A reference probe is used to record the response of the probe. After this aging cycle,

the probe is connected to a the transmitter unit and a calibration cycle with 200°C steam is again carried out. Finally, the probe is introduced into a calibrator. The calibrator consists of a carefully designed isothermal measuring chamber, which is heated to 150°C. The chamber is evacuated to 0.1 Pa which defines the zero point of the instrument. A leak test is performed and then water is introduced until a pressure of 2.5 x 104 Pa (100 in. of water) is reached. A second point on the calibration range is then established. By varying temperature and pressure, the long term stability is tested. Temperature and pressure measurements are made by NIST traceable instruments and methods 3. This calibration procedure takes about 2 weeks to complete.

As long as the measuring chamber and the reference chamber are not physically damaged by loss of dimensional integrity, the probe never has to be calibrated again.

6. Applications

6.1 Control Drying Processes
- spray dryer optimization
- direct fired drying
- climate zone regulation in conveyor dryers
- waste gas control in continuous thermal drying
- vacuum drying
- steam drying

6.2 Dewpoint Approach Control
- stacks and ducts
- prevent duct corrosion by condensation

6.3 Dry Scrubbing and Product Removal
- reduce pressure loss due to bag plugging
- reduce waste, energy and down-time
- control flue gas de-sulfurization

6.4 Moisture Content in Flue Gases
- control combustion processes
- detect boiler leaks
- control NOx removal processes
- correlate emission parameters

6.5 Electrostatic Precipitator Conditioning
- enhance particulate collection by moisture injection
- control moisture to avoid corrosion and buildup

6.6 Blast Furnace Combustion Processes
- monitor moisture intrusion for safety
- prevent bag-house plugging and down-time
- control water spray systems

6.7 Chemical Manufacturing
- silica gel, sodium chloride (salt), ceramics
- ferrous oxide (magnetic tape coating)

7. Conclusion

The fundamental advantage of this instrument is that it allows an accurate and reproducible measurement, even at elevated temperatures and high particulate loading. The probe has no moving components, semiconductor circuits or chemically reactive substances.

Important challenges for process moisture measurement (sampling, temperature, particulate, calibration, interference and corrosion) are successfully addressed by the H2O Moisture Analyzer technology.

The H2O Moisture Measurement Technology

makes possible what many process specialists

have believed is impossible - "inherently-accurate"

continuous moisture measurement.

8. References

1.	Wexler, A., Calibration of humidity-measuring instruments at The National Bureau of Standards, ISA Trans., 7, No. 4, 356-368 (1968)
2.	Von Hippel, Arthur R., Dielectrics and Waves (Artech House, 1995)
3.	Goff, J.A., Saturation pressure of water on the new Kelvin scale. Humidity and Moisture, Vol. III, A. Wexler (ed.) (Reinhold Publishing Corp., N.Y., 1964), pp.289-292

9. Specifications

9.1 Probe

Maximum Operating Temperature: 851°F (455°C) - higher temperature measurement option available.

Maximum Operating Pressure: 1000PSI (68atm) - higher pressures and vacuum options available.

Operating Range: 0-100% absolute volume, smaller ranges available.

Response Time: 20 seconds to 95%FS

Measurement Error: +/- 0.25% typical (depends on range and temperature; 5% of range maximum)

Materials in contact with process: (Some or all of the following): Inconel 600, Inconel 718, Stainless Steel, Aluminum, PTFE, Al2O3 Ceramic,Viton

9.2 Sensor Circuitry

Output Signal: 4..20mA

Protection Type: IP65 to DIN 40 050

Power Requirements: 120V 15A; higher ratings may be required for special options.

9.3 Transmitter Unit

Ambient Temperature: 0 to 90°C (32 - 200°F)

Climate: Max. 80%RH (non-dewing)

Rating: NEMA 4 Equivalent (Others Optional)

Electromagnetic Compatibility: Corresponds to CISPR 11 Class 1, CDE 871 K (Line Malfunctions)

Interference Radiation: Corresponds to MIL STD 461 B, Class B

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