Techniques for Fast Measurements of Low Dewpoint in Portable Hygrometers

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Abstract

Measurement of moisture or dewpoint is vital in many applications and industries. Many measurements of dewpoint are performed by service personnel using a portable dewpoint hygrometer based on ceramic or aluminium oxide sensor technology. When making a measurement of dewpoint an instrument can take several hours to provide an accurate measurement due to the need to purge the sensor of water vapour molecules, and the surrounding sampling pipe work, of any water vapour. This is acceptable in an instrument that is permanently installed in the gas stream but not for a portable dew point instrument.

In the past manufactures of such instruments have stored the sensor in a desiccant material. This dries the sensor over time and can provide a fast response. However this can have long term affects on the sensor calibration and subsequent measurements are still subject to long response times.

Michell Instruments investigated methods of how to decrease the waiting time between measurements. The objective was to examine if a combination of changes to the sensor design, and data handling can reduce the time between measurements to less than 15 minutes.

To achieve this, Michell Instruments utilises three separate techniques, sensor preconditioning, sensor heating / purge and predictive software to ensure that dew point measurements are available to the user in less than ten minutes, for every measurement not just the first.

Comprehensive testing over a wide range of dewpoint levels have shown that these three techniques, when used together, can consistently and accurately provide measurement to -80 °C within 10 minutes of the measurement being initiated.

Future studies will focus on the further improvement of ceramic sensor response speed and refinement of the software algorithms. The project will contribute to future research on improvement moisture and dewpoint sensor technologies.

Learning Objectives

The attendee will learn the problems associated with making repeat measurements with a portable dewpoint hygrometer, and the various techniques designed, tested and utilised by Michell Instruments to overcome these problems.

The attendee will be able to use this knowledge to understand the importance of such measurements and will be able to appreciate the advantages and disadvantages of various different dewpoint measurement techniques.
1. Introduction

Measurement of moisture or dewpoint is vital in many applications. For example, measurement of moisture in air dryers is an accepted method of cost and energy savings in compressed air generation. It is important to precisely know the dew point levels at which the dryer is switching the dryer column.

Such measurements are usually performed by service personnel using a portable dewpoint hygrometer based on ceramic or aluminium oxide sensor technology. When making a measurement of dewpoint an instrument can take several hours to provide an accurate measurement due to the need to purge the sensor, and the surrounding sampling pipe work, of any water vapour. This is acceptable in an instrument that is permanently installed in the gas stream but not for a portable dew point instrument.

In the past manufacturers of such instruments have stored the sensor in a desiccant material. This dries the sensor over time and can provide a fast response, FOR THE FIRST MEASUREMENT. However subsequent measurements are still subject to long response times. There are also long term problems with the sensor calibration due to continued desiccation.

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To achieve this, Michell Instruments utilises three separate techniques, sensor preconditioning, sensor heating / purge and predictive software to ensure that dew point measurements are available to the user in less than ten minutes, for every measurement not just the first.

Comprehensive testing over a wide range of dewpoint levels have shown that these three techniques, when used together, can consistently and accurately provide measurement to -80 °C within 10 minutes of the measurement being initiated. Moreover each measurement receives the same treatment and therefore is just as fast as the previous measurement.

Future studies will focus on the further improvement of ceramic sensor response speed and refinement of the software algorithms. The project will contribute to future research on improvement moisture and dewpoint sensor technologies.

2. Response of Unmodified Sensor

To understand the problem and solution we must first look at the mechanism by which the ceramic dewpoint sensor measures dewpoint and in particular the way in which it responds when exposed to a change in dewpoint, whether this is a dry to wet or a wet to dry change.
2.1. Ceramic Moisture Sensor

The ceramic moisture sensor shown in Figure 1 is a proprietary technology of Michell Instruments Ltd, U.K. This sensor has a metallised ceramic structure, produced from base metals using thick and thin film techniques onto a stable semiconductor grade ceramic base as shown in Figure 2 below. The sensor can be considered to function as a moisture sensitive capacitor, where moisture from the sample gas flow is freely able to permeate through one plate of the capacitor (in this case a coarse grain vacuum coating of pure gold) into the dielectric layer beneath, which has hygroscopic properties.
Due to the polar nature of the moisture molecule, the sensor exhibits a change in impedance dependant on the amount of moisture vapour adsorbed into this hygroscopic surface, which is in constant equilibrium with the concentration of moisture within the sample gas being measured. The sensor impedance changes in response to the partial pressure of water vapour, for which there is a direct relationship with dewpoint temperature, so enabling the sensor to be calibrated to provide accurate measurement of the dewpoint temperature irrespective of prevailing analysis pressure and temperature conditions.

The response characteristic for each sensor varies typically from 45K Ohms at –100°Cdp down to 5K Ohms at +20°Cdp and is mapped for each individual sensor at time of calibration. Within the Michell range of products utilising the ceramic sensor, digital linearization techniques are used to achieve an accuracy of within +/-1 to 2°Cdp across the whole measurement range, with certified calibration traceable to NPL (UK) and NIST (USA).

2.2. Response Times

The ceramic sensor competes in the market with a number of similar sensor technologies, including aluminium oxide, silicon oxide and phosphorus pentoxide. All of these sensors have a response which means that it can take several hours for the sensor to provide a stable response to low dew points. This response can be affected by the design and material of any sampling system but is mostly an inherent property of the sensor itself.

Figures 3 and 4 below show typical response times for different dewpoint values

![Typical Sensor’s Response: +15°C dp to -41°C dp](image)

Figure 3 – Sensor response from +15 °C dewpoint to -41 °C dewpoint.
Figure 4 – Sensor response from +10 °C dewpoint to -60 °C dewpoint.

These response times are acceptable for instruments which are permanently installed and continuously exposed to the sample gas. One of the reasons for this is the response exhibited when the sensor is wetting up which is much quicker as can be seen in Figure 5 below. This means that a sensor can rapidly measure a sudden rise in dew point or moisture content, which is the requirement for 75% of industrial dew point measurement applications. Other applications which need to track and adjust a varying dewpoint can also be undertaken with a permanently installed sensor as the process changes are slow, and the ceramic sensor response acceptable.

Figure 5 – Sensor response from -50 °C dewpoint to -30 °C dewpoint.
However the dry down times shown above are impracticable for a portable instrument. Without and modification to the sensor or changes to the measurement process only one measurement of -60 °C dewpoint or lower would be possible in a working day.

3. Design Considerations for Sensor for Portable Dewpoint Meter

There are several factors to take into consideration when designing a portable dewpoint meter to provide the fastest possible response. Figure 6 below shows the sensor assembly currently used by Michell Instrument for portable dewpoint meters.

![Figure 6 – Michell Instruments sensor assembly.](image)

3.1. Minimum Volume

To maximise the effect of the purging if the sensor by the dry sample gas, the volume of the sensor assembly needs to be kept to a minimum. This is equally true for the sensor chamber and the connecting pipe work.

3.2. Minimum Surface Area

Along with minimising the volume a small sensor assembly will also have a smaller surface area. This in turn minimises the number of water vapour molecules which are absorbed into the surface layer of the sensor assembly when the sensor assembly is exposed to wet gas. These molecules will be returned to the gas flow when a dry gas is passed through the sensor assembly, slowing down the rate at which the whole sensor assembly can be dried.
3.3. Materials

The material of construction chosen for the gas wetted parts of a dewpoint sensor assembly can have a marked effect on the response times.

As can be seen from Figure 7 below, materials such as stainless steel and PTFE exhibit much reduced hygroscopic properties when compared to nylon or copper.

![Figure 7 – Comparison of effects of different sampling materials.](image)

All the considerations mentioned in this section have been widely understood for some years and have lead to better response to low dew points for portable hygrometers. However Michell Instruments have made several further steps in the improvement in response as is discussed below
4. Sensor Pre-conditioning

All secondary type moisture sensors work on the same basic principles, that is to say they are all based on a capacitor structure with one or more porous plates combined with a moisture sensitive dielectric. The capacitance, $C$, of a dielectric between a pair of parallel plate electrodes is given by

$$C = \frac{\varepsilon_0 \varepsilon_r A}{t}$$

Where $\varepsilon_0$ is the permittivity of free space, $\varepsilon_r$ is the relative permittivity or dielectric constant, $A$ is the area of the electrodes and $t$ is the distance between the two conducting plates.

Because the surface plate(s) of the capacitor are porous, water vapour penetrates into the film, where it may be absorbed onto the surfaces of the pores. As water is highly polarised, this absorption of water leads to a dramatic increase in $\varepsilon_r$, the magnitude of which is directly proportional to the amount of water absorbed, and hence the moisture content.

However, it is commonly observed that the output of such sensors tends to drift with time, meaning that sensors require periodic recalibration in order to retain suitable accuracy. It is also commonly noted that operation of these types of sensor at elevated temperature increases the rate of drift.

In a portable dewpoint meter, as is explained in more depth in section 5, it is advantageous to heat the sensor significantly above the temperature of the sample gas in order to desiccate the sensor dielectric relative to the gas stream (and sample system) in order to effect a localized purge at the start of the measurement cycle.

This typically creates a dilemma, heating the sensor will benefit response time but will also result in accelerated drift, which negates accuracy.

As part of their fundamental research programme Michell Instruments developed a novel pre-conditioning mechanism that changes the physical structure of the sensor dielectric such that the morphology changes that classically occur on heat cycling and that are associated with long term measurement drift are minimised to the point where their effects are minimal on overall measurement uncertainty. As a result Michell Instruments have been able to use the heating and purge cycling technique described in section 5 with no detrimental effect on the long term stability of the sensor.

5. Sensor Heater and Purge

The pre-conditioning of the ceramic sensor previously described in section 4 allows the sensor to be heated to a maximum temperature of 70 °C. This along with the purge effect of the dry gas causes the sensor to dry down to a point below the dewpoint to be measured. Once the heater is switched off the water vapour molecules are re-adsorbed into the structure of the sensor.
5.1. Heater

The ceramic sensor assembly used by Michell Instruments for portable dewpoint meters in utilises the resistive heater that is integrated into the ceramic sensor. Figure 8 below shows the Michell Instruments ceramic sensor and the resistive heater grid can clearly be seen on the sensor surface. This allows the sensor to be heated to 70 °C as part of the sensor initialization. This initialization period is set at 3 minutes but can be adjusted by the user.

![Figure 8 – Ceramic sensor showing heater grid.](image)

5.2. Heating Cycle

By heating the sensor above the temperature of the incoming sample gas we effectively dry the sensor i.e. fewer water vapour molecules adhere to the sensor. The higher the temperature of the sensor and the longer the time for which it is heated, the greater the degree of drying of the sensor relative to the sample gas to which it is exposed.

When the heating source is switched off the sensor temperature reduces to that of the sample gas and water molecules are re-adsorbed onto the sensor surface i.e. The sensor ‘wets-up’.

This is by a diffusive mechanism which is time dependent. However, a relatively dry sensor will ‘wet-up’ to the dew point of the sample gas many times faster than a relatively wet sensor will ‘dry-down’ to the dew-point of the sample gas. This is partly due to the excess energy released when gaseous water vapour molecules (which have 3 degrees of motion) in the sample gas are adsorbed onto the sensor surface (having only 2 degrees of motion) – the ‘heat of adsorption’.

Michell Instruments have found that heating the sensor to 70 °C for 3 mins is sufficient to dry the sensor to approximately -80 °C dew point when the sensor has cooled back to 30 °C.
In Figure 9 below we can see the output of the sensor when exposed to a heater cycle of 3 minutes.

From 0 to 3 minutes the sensor is heated and the dewpoint indicated by the sensor is reduced to below -30 °C. However this is higher than the actual dewpoint seen by the sensor, due to the effect on the sensor of the higher temperature. From 3 to 4.5 minutes the sensor cools rapidly and the indicated dewpoint falls, in this case to approximately -60 °C dewpoint. From 4.5 to 10 minutes the sensor rapidly re-adsorbs the water vapour molecules and settles at the actual dewpoint of the gas sample.

When compared with the response of the un-modified sensor as seen in figure 1 the reduction in response time is dramatic and makes the portable instrument a much more practical proposition.

Figure 9 – Response of ceramic sensor to heater / purge cycle.

Combined with the dewpoint prediction algorithm (see section 6) this heater purge cycle provides an extremely fast response to dewpoint down to -70 °C dewpoint.
6. Quick Response Algorithm

Michell Instruments have also been able to improve the response of a portable dewpoint instrument by manipulating the data produced as part of the heating, purge and wetting up process described in section 5.

6.1. Wetting-up Process

Once the sensor has been heated and purged the indicated dewpoint will reach a minimum value (At about \( t = 3.5 \) minutes in Figure 9 above). From this point the sensor will begin to “wet up” as the water molecules return to the sensor. This diffusive process is a complex phenomenon and the rate of wetting up will depend on several factors, such as the dewpoint of the sample gas, minimum indicated dewpoint and the individual characteristics of the sensor.

6.2. Algorithm

Experimental results have demonstrated that a first-order response curve of the form:

\[
Dew\ Point = a + b e^{-t/\tau}
\]

Where \( t \) is the elapsed time and \( a, b \) and \( \tau \) are constants, adequately describes the behaviour of the sensor during the wetting up phase.

Using a transformation of this equation Michell Instruments are able to directly estimate the constant ‘\( a \)’, which represents the final, steady-state, dew point of the reading of the sensor. We are able to accomplish this using data from the initial part of the sensor wetting-up curve only. (Between 3.5 and 5 minutes on the example curve in Figure 9)

6.3. Calculation

Once the heater / purge cycle described in section 5 is completed the indicated dewpoint begins to rise as the wetting up process “takes over”. The data received from the sensor is thus used in a transformation of the algorithm given in section 6.2. This allows the instrument to quickly calculate the final stable dewpoint that the sensor, further reducing the response of the instrument.

This is shown in Figure 10 below. From the trough of the curve at approximately 3.5 minutes the final stable dewpoint is calculated. At approximately 4 minutes there is sufficient data gleaned from the wetting-up process for the calculation to be acceptable and at this point the instrument would display the measured dewpoint.
7. Practical Application

Michell Instruments have utilised the three techniques described in the design of the MDM300 Advanced Dewpoint Hygrometer. This instrument was launched in May 2009.

8. Results

Figure 11 below summarises the results found when more than 100 sensor assemblies were tested across the range of dewpoint from 0 to –80 °C dewpoint
9. Further Work

Michell Instruments will continue to improve the performance of the ceramic sensor with research into the following:

9.1. Materials of Construction

The materials used in both the ceramic sensor itself and the sensor assembly will be reviewed and tested to understand their part in how the sensor responds, and if modifications can be made that will further improve response times.

9.2. Closer Control of Sensor Temperature and Purge Flow Rate

Michell Instruments recognise that closer control of the sensor temperature and purge flow rate can provide a more constant wetting-up process, which in turn could lead to further improvements in the speed of response.

9.3. Improvements in the Effectiveness of the Quick Response Algorithm

With more collected data Michell Instruments continue to work on the quick response algorithm to improve its effectiveness and constancy.
10. Conclusions

Michell Instruments have proved that with a combination of closely controlling the manufacturing process for the ceramic sensor, heating / purging the sensor to dry it and then using the algorithm given in section 6.2 it is possible to design a portable dewpoint meter which can accurately and repeatable measure to very low dew points with a T95 figure of less than 10 minutes.

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May 2010