



## Long-term study of the durability of dew point sensors for dry conditions

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### **Abstract**

This paper examines the long-term performance and durability of various dew point sensors under extremely dry conditions. Over a period of six months sensors were tested for stability, response time, and drift behaviour. The results confirm that sensors only operate reliably within their specified ranges and that applied measurement algorithms have a greater impact on performance than the sensing principle itself.

Index Terms—Dew Point Sensor, Drift, Response Time, Sensor Durability.

## I. INTRODUCTION

Next-generation batteries show a rising sensitivity to ambient humidity during their production process [1]. An advanced and constant system control leads to a higher output in consistency and quality. This causes an increasing demand for advanced drying systems. Weiss Klimatechnik GmbH has developed the dryer Vindur DryCell capable of achieving dew points below  $-60\text{ }^{\circ}\text{C}_{\text{DP}}$  to meet the stringent requirements of such applications. A dew point, measured in  $^{\circ}\text{C}$  or  $^{\circ}\text{C}_{\text{DP}}$ , is the temperature at which air is saturated with moisture and water vapour begins to condense into liquid. The dew point is therefore a method of measuring humidity. This kind of measurement is particularly useful for extremely low humidity levels as it scales proportionally compared to other significant measures such as temperature.

Measurement of these dew points is essential but challenging due to the extremely low humidity levels in the air (less than 100 ppm) [2] which are below the accuracy of conventional sensors. As of now, there is a variety of specialised sensors available on the market. However, they lack intercomparability due to different measurement methods, autocalibration algorithms, response times and drift behaviours.

For this reason, it was decided to carry out a long-term test in which the reaction speeds and long-term stability were analysed to qualify and validate the performance of several sensors. Particular attention was paid to the differences in the performance of the individual measuring elements and to anomalies during the course of the measurement. The remainder of the paper is structured as follows: In Chapter II the methodology and study design regarding the test setup and its analysis criteria is described. In Chapter III the test results will be discussed regarding long-term behaviour and step response times. The last Chapter concludes with a summary of the findings and gives an outlook for future research.

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## II. METHODOLOGY AND STUDY DESIGN

### A. Decision criteria and uncertainties for inter-compatibility

Eleven different sensors from nine manufacturers were initially considered for the test. In a decision matrix the sensors were observed regarding the dew point scaling range which should cover the range around  $-60\text{ }^{\circ}\text{C}_{\text{DP}}$ , accuracy, response times, metrological criteria such as the measuring principle, communication interfaces, process connections, calibration cycles and price. It became apparent, that they differed greatly in all the criteria so that no standard could be determined for those sensors. Although the sensors can work under extremely dry conditions in theory, manufacturers have, according to their own statement, limited experience in this area, too. Limited experimental data, particularly in the area of longterm stability under extremely dry conditions is a common challenge. On the other hand customers expect a high sensor reliability and fast response times to maximise production output with their processes. This paper has been initiated by the question whether the measuring principle of a sensor is the leading characteristic for the sensor quality.

### B. Test setup and procedure

From the selection of possible sensors and the evaluation of the decision matrix, it was decided to acquire six sensor for the actual test. In the second test phase three new sensors were added to be investigated. The reasons will be stated in Chapter III. The following test setup was developed to analyse the long-term stability and response velocity of the sensors: All sensors were set up for measurement in dry conditions between  $-78\text{ }^{\circ}\text{C}_{\text{DP}}$  and  $-40\text{ }^{\circ}\text{C}_{\text{DP}}$  for a period of 6 months. In the first phase the dew point was between  $-60\text{ }^{\circ}\text{C}_{\text{DP}}$  and  $-40\text{ }^{\circ}\text{C}_{\text{DP}}$  and in the second phase the dew point was kept at  $-78\text{ }^{\circ}\text{C}_{\text{DP}}$  continuously. In the following document, the unit  $^{\circ}\text{C}_{\text{DP}}$  will be used for the dew point to distinguish it from the temperature in  $^{\circ}\text{C}$ . The test takes place in a climate chamber that ensures a constant ambient temperature of  $20\text{ }^{\circ}\text{C}$ . Dry air is provided by a compressed air treatment system, which takes air from the building and dries it. The sensor measurement data is recorded continuously via a milliampere interface and is translated linearly to a dew point value in the data logging system.

The six-month test was divided into two phases of three months each. At the end of each phase, the step responses of the sensors from dry to humid and vice versa were recorded. To ensure the reliability of the step response measurements, each experiment was repeated multiple times until the form of the step responses stabilised and became reproducible. This was achieved by a comparison within the recorded responses. The long-term stability was analysed at the end of the six-month period by comparing the final calibration with the calibration certificates provided at the time of purchase.

### C. Criteria for analysis

The following criteria are particularly interesting for the analysis: Firstly, in order to increase process reliability, this paper investigates whether and to which extent the sensor measurements drift over time, providing a data-driven indication and recommendation on proper calibration intervals.

Secondly, step responses are of particular interest, as the sudden exposure of significant amounts of moisture, also referred to as 'moisture incident', may have a significant impact on production quality and consistency [1]. Therefore, a prompt and accurate detection of sudden changes in humidity levels, such as a jump from dry to humid, must be provided. In this context, based on the high air exchange rate, it is also important to know when a stable final value can be reached again after the incident. A stable condition was defined as a derivation of maximum of ten percent from the expected value.

The influence of auto-calibration algorithms on measurements is also of great interest to understand the quality of the given values. Some manufacturers integrate these autocalibration algorithms in their software to increase long-term stability. To achieve this, the sensor element is heated up so that the moisture can be heated out and the slope of the scaling line is adjusted to the resulting virtual moisture-free point [3]. This is usually accompanied by a measurement interruption in the range of up to one minute. The manufacturers do not give details about the auto-calibration intervals but they can be seen in quick changes in the readings.

### D. Sensor specification

In the first phase of the long-term test, six sensors were tested, which are listed in Table I. They differ essentially in their measuring principle used and the specified measuring ranges

Table I: Sensor Specifications Phase I.

| Measuring Principle                                   | Sensor | Specified Range / °C <sub>DP</sub> |
|-------------------------------------------------------|--------|------------------------------------|
| Polymer                                               | #1     | 0 ... -60                          |
|                                                       | #4     | +20 ... -80                        |
| Aluminium Oxide (Al <sub>2</sub> O <sub>3</sub> )     | #2     | 0 ... -80                          |
|                                                       | #6     | +20 ... -80                        |
| Electrolytic Resistive                                | #3     | +80 ... -20                        |
| Phosphorus Pentoxide (P <sub>2</sub> O <sub>5</sub> ) | #5     | -20 ... -100                       |

Sensors #1 and #4 are polymer sensors and sensors #2 and #6 are based on aluminium oxide. The specified measuring ranges of these sensors are between +20 °C<sub>DP</sub> to -80 °C<sub>DP</sub>. The measuring principles of the following sensors are not very common and therefore especially noteworthy: Sensor #3 works on the basis of an undefined 'electrolytic resistive' measuring principle and has a measuring range of +80 °C<sub>DP</sub> to -20 °C<sub>DP</sub>. According to the manufacturer's qualification tests, this sensor is particularly suitable for humid environments but can also be used outside the specified range at extremely low dew points. This should be reviewed in these tests. Sensor #5 works on the basis of phosphorus pentoxide and has a measuring range of -20 °C<sub>DP</sub> to -100 °C<sub>DP</sub>. Based on the measuring principle, it is expected, that this type of sensor is particularly stable compared to Aluminium Oxide based sensors over the long term and that it shows accurate values at extremely low dew points.. Table II shows the additional sensors in test phase II. All these sensors operate within their specified range and are polymer-based sensors.

Table II: Additional Sensors Phase II

| Measuring Principle | Sensor | Specified Range / °C <sub>DP</sub> |
|---------------------|--------|------------------------------------|
| Polymer             | #7     | +20 ... -100                       |
|                     | #8     | +20 ... -80                        |
|                     | #9     | +20 ... -80                        |

### III. RESULTS AND DISCUSSION

#### A. Analysis of long-term behaviour

##### 1) Phase I:

The recorded data from phase I quickly showed that four of the sensors were not suitable for the use cases. Initially, it became apparent that it was not possible to operate the sensors outside their specified measuring range, even if the manufacturer stated otherwise. Sensors #1 and #3 froze their readings at its range value as soon as they left the specified measurement range and did not change.

Sensors #5 and #6 showed failures even though they were operating within their specified measurement range. Sensor #5 began to oscillate heavily after 19 days and completely failed after 44 days. The output value of sensor #6 spontaneously toggled between the end values of the measurement range since the beginning of the experiment, occasionally providing more realistic values in between. Figure 1 shows an excerpt from the measurement data of the first phase.

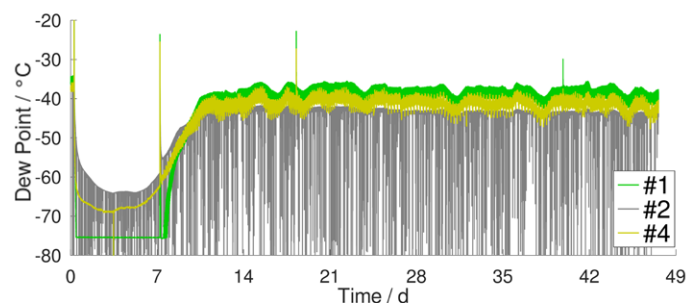


Figure 1: Excerpt Phase

Sensor #1 is depicted in green, operating outside its specified range at a dew point below  $-60\text{ }^{\circ}\text{C}_{\text{DP}}$ . Sensor #2, shown in gray, repeatedly hit its lower measurement range limit due to a firmware issue. This problem was resolved by the manufacturer afterwards and did not occur anymore.

At a dew point of  $-40\text{ }^{\circ}\text{C}_{\text{DP}}$ , sensors #1 and #4 exhibit oscillatory behaviour. It is assumed that these oscillations are caused by the compressed air preparation, as the two affected sensors respond relatively quick to changes in the dew point (see Chapter III-B) and oscillate in phase. In summary, at the end of the first test phase, only sensors #2 and #4 were found to be of further interest for the mentioned use case.

##### 2) Phase II:

Since the disproportionate reduction of sensors named in Phase I was not expected, new sensor types were subsequently considered for this analysis. As a result, three additional polymer-based sensors were included for the second phase. It was a coincidence that the added sensors were polymerbased sensors which shall not give a statement on the quality due to the measuring principle. The second test phase did not provide any new insights for sensors #2 and #4, besides the firmware fix of sensor #2. Therefore, these are not discussed any further.

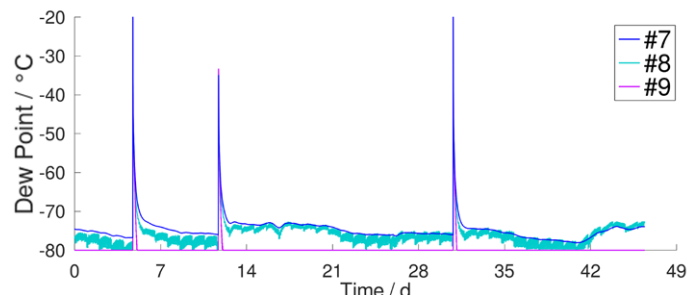


Figure 2: Excerpt Phase II

Figure 2 shows an excerpt from the long-term data of the second phase. Sensors #7 and #8 show reliable behaviour. However, sensor #8 oscillates significantly more than all other sensors. It also repeatedly shows slopes in the measured value, which may be caused by cyclical auto-calibrations. Sensor #9, shown in violet, falls to its lower measurement range limit at dew points below  $-70^{\circ}\text{C}_{\text{DP}}$ , even though it is still within the specified range. A consultation with the manufacturer revealed that they are already working on a solution to this problem. To conclude, it can be said that based on the accuracy and quality of the measurement in the long-term test, both sensor #7 and sensor #8 delivered promising results. Even though both are Polymer based sensors, no general recommendation can be made between the measuring principle and the quality. The two sensors are therefore shortlisted together with sensors #2 and #4 from the first test phase.

#### B. Analysis of step responses

The step response behaviour of the tested dew point sensors was analysed after each of the two experimental phases. Step responses illustrate how a sensor reacts to sudden changes in input, such as a step from dry to humid air. They are an important indicator of the sensor's dynamic performance [4]. By analysing the time it takes for the sensor to detect and stabilise after such a change, one can assess its responsiveness, accuracy and suitability for real-time applications. These characteristics are especially important in the given use case, when humidity rises and falls within seconds.

The results can be found in Table III and IV for each phase. The variability in step response times among the tested sensors was not expected.

Table III: T90 Step Response Times in Phase I

| Sensor | T90 / s dry → humid | T90 / s humid → dry |
|--------|---------------------|---------------------|
| #1     | 0.56                | 75.8                |
| #2     | 5                   | 375                 |
| #4     | 2.8                 | 6.8*                |

Table IV: T90 Step Response Times in Phase II

| Sensor | T90 / s dry → humid | T90 / s humid → dry |
|--------|---------------------|---------------------|
| #1     | 0.61                | 92.6                |
| #2     | 11.21               | 317.6               |
| #4     | 2.3                 | 7.1*                |
| #7     | 60.3                | 321.8               |
| #8     | 5.3                 | 367.5               |
| #9     | 10.4                | 359.4               |

\*Unreliable value due to instabilities caused by auto-calibration routines during humid-to-dry step.

Differences of greater than a factor of 20 between models were noted. Transitions from dry to humid conditions consistently occurred faster than those from humid to dry. Particularly notable were sensors #1 and #4, which exhibited 0-to-90% step-times of only a few seconds. In contrast, sensors #2 and #7 were among the slowest in the test group. No consistent correlation could be established by measuring principle of the sensor. This leads to the assumptions that this can be attributed to the overall measurement algorithms.

It was observed that the sensors generally tend to measure slower over time. While this effect was minor for most devices, i.e. only a few percent, sensor #2 showed a dramatic increase in response time of over 100 %, indicating a significant degradation in performance. This suggests that the sensor quality can deteriorate with use, which is critical for longterm deployment.

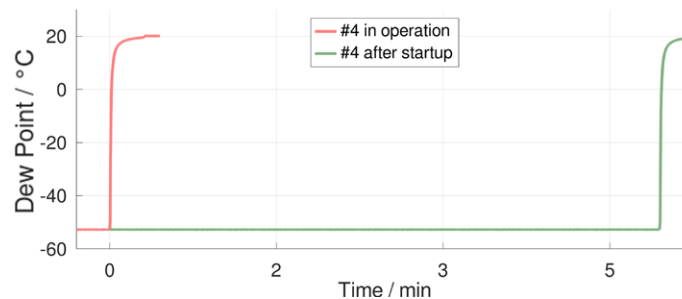


Figure 3: Dead times

In many cases, dead times, shown as a constant and not changing value of up to six minutes were recorded, particularly following auto-calibration routines or shortly after startup. Figure 3 shows this for sensor #4, both immediately after startup and during operation. These periods of unresponsiveness and faulty measures may impact continuous monitoring negatively and should be accounted for in measurement strategies.

Another important observation was the settling behaviour of the sensors. Depending on the scenario, it could take up to an hour for the readings to stabilise after a step change. The steady state is defined as a condition in which a system's value remains constant over a significant time period. Figure 4 shows the settling curve of sensor #4 during a transition from humid to dry conditions.

At the beginning of the curve shown in Figure 4, a very rapid drop in the measured value is visible, indicating the sensor's initial responsiveness. However, around  $-50^{\circ}\text{C}_{\text{DP}}$ , the first auto-calibration event occurs. From that point on, the sensor progresses only slowly, freezing its output several times for multiple minutes in total. It is not until nearly seven minutes that the sensor abruptly jumps to the expected end value. It would be preferable if the sensor would provide a continuous output signal, as freezing the output prevents the measured value from falling continuously. Even if the stable end value were to be reached within the same time interval, a continuously falling measured value would be more favourable, both economically and in terms of control technology.

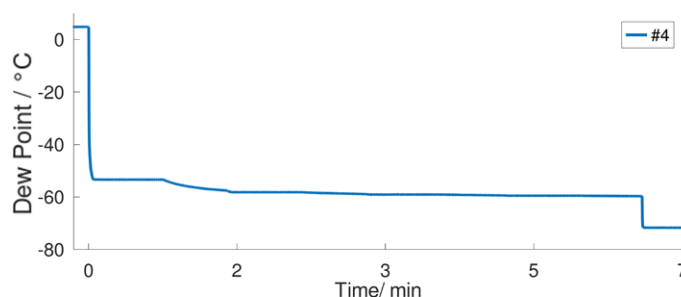


Figure 4: Settle curve

Interestingly, the speed of response did not correlate clearly with the underlying measurement principle. For example, sensor #1, which uses a polymer-based sensing element, was found to be approximately 15 times faster than #9, which also uses polymer technology. Conversely, sensor #7 (polymer) responded around six times slower than sensor #2, which is based on Al<sub>2</sub>O<sub>3</sub>. It can be assumed that the internal signal processing algorithms play a more decisive role in determining response speed than the sensor material alone.

### C. Analysis of drift behaviour

Based on the results, it is difficult to make a definitive statement about how the sensors behave when they drift, as it is not possible to accurately account for external influences, such as fluctuations in the dew point within the climate chamber. However, an emerging trend appears to be evident: the longer a sensor remains under dry conditions, the more pronounced the drift tends to be. It seems the sensors become less responsive in dry environments, potentially accelerating ageing or degradation. In some cases, the observed drift even exceeded the specified measurement uncertainty. This was particularly evident for sensor #4 after more than six months in operation, and for sensor #7, which showed similar deviations after only three months. Therefore, manufacturers' calibration cycles must be adhered to. A calibration at least every twelve months appears reasonable.

## IV. SUMMARY AND CONCLUSION

The long-term study of dew point sensors under extremely dry conditions aimed to evaluate the stability and responsiveness of various sensor types over a six-month period. A total of nine sensors from different manufacturers were tested throughout two phases in a controlled environment between  $-78\text{ }^{\circ}\text{C}_{\text{DP}}$  and  $-40\text{ }^{\circ}\text{C}_{\text{DP}}$ . The study revealed significant differences in performance: some sensors failed early or showed erratic behaviour due to unknown reasons, while sensors #2, #4, #7 and #8 maintained reliable operation. Key findings included a notable drift in sensor readings over time, especially under prolonged dry conditions and considerable variation in response times. Some sensors exhibited delays of several minutes due to physical processes and auto-calibration routines. For the current offer of sensors, battery cell producers need to consider this when changes in humidity occur. A defined waiting time must be taken into account until the reading can be accepted for the ongoing process.

It became evident during the long-term test, that the internal measurement algorithms play a more decisive role in determining the overall performance of a sensor than the physical measuring principle alone. Additionally, the study clearly demonstrated that sensors only function reliably within their specified measurement ranges, attempts to operate them outside these limits led to failures or erratic readings. To conclude, sensor #4 was found to operate well for dew points below  $-60\text{ }^{\circ}\text{C}_{\text{DP}}$  while sensor #8 can be used for dew points between  $-60\text{ }^{\circ}\text{C}_{\text{DP}}$  and  $-40\text{ }^{\circ}\text{C}_{\text{DP}}$ . Based on the test results, both named sensors generally perform well regarding drift behaviour, step response times and reliability.

Looking ahead, the sensor market should be closely monitored, especially as developments in uninterrupted measurement technology are progressing rapidly and could offer new and more robust solutions for critical applications such as battery cell production. However, there is a trend that dew point sensor manufacturers are working on improving the sensor quality, as seen in software updates.

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