Response Characteristics of Dew Point Hygrometer by Connection Order in Series in Calibration

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Abstract—**In this study, we present the respective calibration set up and procedure with serial connection for dew point hygrometers with chilled mirror and aluminum oxide types. To evaluate in more detail the response characteristics according to dew point hygrometers by connection order in series, the variation of measured dew point temperatures and uncertainty contribution rate due to the connection order of hygrometers were investigated for two types of hygrometers the most widely used. We suggest treatment method for measurement deviation caused by multiple series connection and appropriate connection method due to dew point hygrometer types. The calibrations were conducted according to standard calibration procedure of Korea Testing Laboratory accredited from ILAC (International Laboratory Accreditation Cooperation) and KOLAS (Korea Laboratory Accreditation Scheme).**

Index Terms—**dew point temperature, connection order, calibration, measurement uncertainty, uncertainty contribution**

I. INTRODUCTION

Humidity influences various fields of industry relevant to sensitive product and materials to moisture contents in the air. The moisture contents in the air play a role in quality assurance of product such as semi-conductor and display, freshness for food and medicine, prevention of hydrates and condensation, corrosion and prevention of liquids of structures [1-3]. Dew point temperature has usually used to calculate absolute humidity in the air as well as relative humidity by saturated water vapor pressure [4,5]. the effectiveness verification of dew point hygrometer is key agent in obtaining the reliability of the measurement results of moisture contents. Consequently, traceability of hygrometer should be maintained through calibration based on international standards, ISO/IEC 17025 and regular standard calibration procedure to ensure their effectiveness.

In many national calibration certificate institute, calibrations of chilled mirror hygrometers and aluminum oxide hygrometer have been conducting. Those types of hygrometers are really popular to measure dew point temperature. The chilled mirror sensor (CMS) is the way to detect condensation temperature on the mirror surface and aluminum oxide sensor (AOS) is the way to convert the electrical output with the amount of moisture content [6-7]. The calibration practice of dew point hygrometers takes a long time for reasons of stabilizing time required for respective reference points, purging process as preliminary work, proper fitting and connection among the instruments and significant hysteresis of the hygrometer. The industry level calibration of dew point hygrometer usually takes about two or three days in most of the calibration institutes. To reduce the calibration time, the calibrations have been performed with multiple series connection of several hygrometers under calibration in most of the calibration institutes. It is easy to control flow modulation and provide gas stably to individual dew point hygrometer. Even though this procedure is no doubt help saving calibration time, the connection order of hygrometers in the calibration instrumentation can negatively affect each measurement results. So far, most of the studies have been done mostly developing the new concept of dew point calibration system and improving measurement accuracy by various generators [7-9]. Also, to reduce the measurement uncertainty, the effect of environmental condition such as purging rate, contamination of gas, change of temperature and flow rate on the calibration results have been investigated [10-14].

The most of the national calibration certificate institute have studied to reduce uncertainty for calibration of dew point hygrometer as well as calibrated based on individual standard procedure considered various environmental effects. However, the effect of connection order in series that is less time consuming than one to one comparison method has not been considered in the industry level calibration, because it has been thought that the connection order effect is small, compared with other uncertainty sources. It is necessary that the effect of connection order of dew point hygrometers should be evaluated as the other uncertainty contribution become smaller.

In this study, we present the respective calibration set up and procedure with serial connection for dew point hygrometers with chilled mirror and aluminum oxide types. To evaluate in more detail the response characteristics according to dew point hygrometers by connection order in series, the variation of measured dew

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point temperatures and uncertainty contribution rate due to the connection order of hygrometers were investigated for two types of hygrometers the most widely used. We suggest treatment method for measurement deviation caused by multiple series connection and appropriate connection method due to dew point hygrometer types.

Figure 1. Chilled mirror hygrometer calibration with tubing from gas outlet.

Figure 2. Capacitive aluminum oxide hygrometer calibration with connection in series

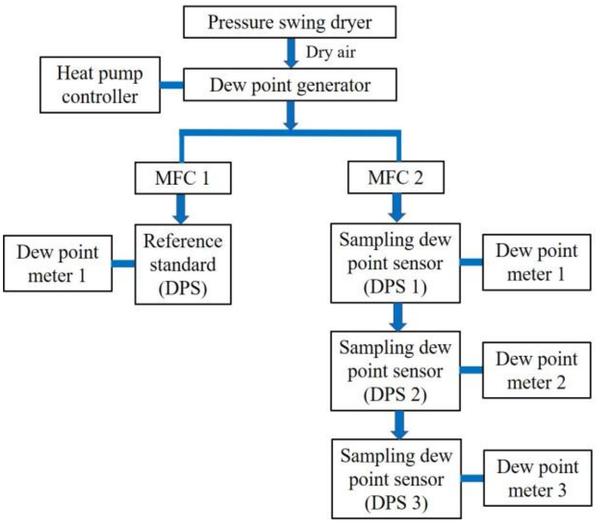


Figure 3. Block diagram of the calibration setup including dew point hygrometer as a reference standard and dew point sensor (DPS)

II. CALIBRATION AND UNCERTAINTY

A. Calibration Instrumentation

The correlation between the series connection order and the type of dew point hygrometer was studied by measuring dew point temperature of chilled mirror sensor (CMS) and aluminum oxide sensor (AOS) during a time period of over a year. The calibration system of dew point hygrometer was composed of mixed flow dew point generator, pressure swing dryer, chilled mirror sensor (CMS) and dew point meter (Fig. 1, 2). Each section is connected by tubing made of stainless steel with the inner diameter of 4 mm. The humid air gas was generated by passing through the cylinder located in the generator filled with water. The dew point of generated humid air gas is determined by mixing dry and humidified air using mass flow controllers set up at individual reference gas and calibration gas outlet of dew point generator. The reference humid air gas was continuously supplied to respective sampling dew point hygrometers and reference dew point sensor simultaneously. The air flow controlled with 0.5 L/min by mass flow controller of calibration gas outlet was introduced to reference dew point hygrometer. whereas, the other air flow controlled with 3 L/min was introduced to sampling dew point hygrometer under the standard condition of 101.325 kPa on all the calibration. Fig. 3 shows the entire schematic diagram of the calibration system for humidity sensors. The same types of sampling hygrometers were connected with each other in series using tubing.

B. Calibration Procedure

The calibrations were conducted for respective three different samples of two hygrometer types with changing connection order at room temperature, (23±0.2) ℃ and a pressure of 1 bar. All of the calibration units including the sampling hygrometers went through purging process for approximately 24 hours as preliminary work to remove residual moisture or absorption in whole system and supply humid gas flow constantly to each dew point hygrometer. Basically, to avoid any condensation inner calibration system, connection tubes and sampling hygrometers, the whole calibration system including sensor bodies, tubes, control valves and flow meters are heated and their temperature always kept higher than the dew point temperature. This means that the condensation effect is minimized by raising the temperature of inner condition of system before changing to reference dew points. Therefore, the operating space of the system was continually maintained above approximately 20 ℃ higher than reference dew point. Also, a simple leak test was performed by closing the air flow tube and monitoring air flow meter, because the measurement errors can be caused by leaks in the entire measurement system. The flow rate flowing into the reference and the sampling hygrometer was maintained constantly. Those minimizes potential error related to condition parameters during air gas transfer. The dew point temperatures were measured in the reference range from -60 ℃ to 10 ℃ with the interval of 10 ℃ and total three outputs with a measurement of three times of six sampling hygrometers. Because chilled mirror sensor (CMS) and capacitive sensor are different from response time and characteristics, we selected commercial sensors from different manufactures as well as stabilization time was taken over 30 minutes at each reference point. The uncertainties including connection order effect as the uncertainty source were estimated for two types of hygrometer at each reference dew point temperature in order to investigate the proportion of uncertainty contribution in the expanded uncertainty.

The calibrations were conducted according to standard calibration procedure of Korea Testing Laboratory accredited from ILAC (International Laboratory Accreditation Cooperation) and KOLAS (Korea Laboratory Accreditation Scheme). The evaluation procedure of measurement uncertainty was also developed in accordance with the principles established in the documents EA-4/02 *Expression of the Uncertainty of Measurement in Calibration* [15].

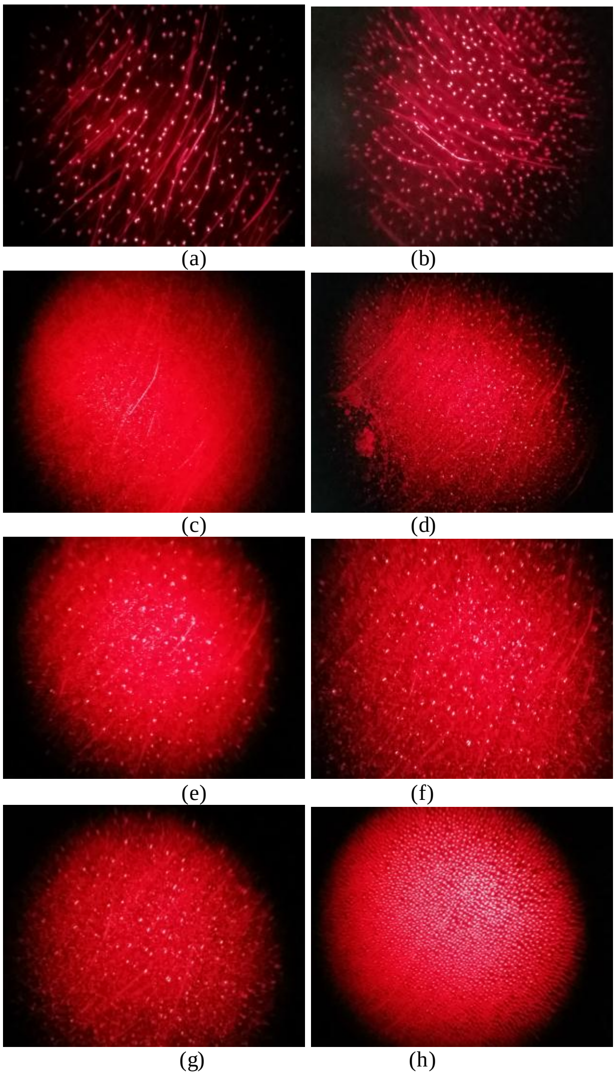


Figure 4. Condensation on chilled mirror with dew point differential in this calibration (a) Dry state caused by full purge, (b) Condensation on mirror with dew point -50 ℃, (c) Condensation on mirror with dew point -40 ℃, (d) Condensation on mirror with dew point -30 ℃, (e) Condensation on mirror with dew point -20 ℃, (f) Condensation on mirror with dew point -10 ℃, (g) Condensation on mirror with dew point 0 ℃, (h) Condensation on mirror with dew point 10 ℃

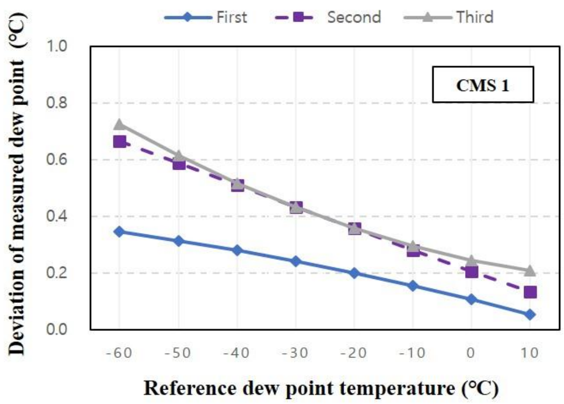
III. Results and Discussion

A. *Variation of Measured Dew Point Due to series Connection Order*

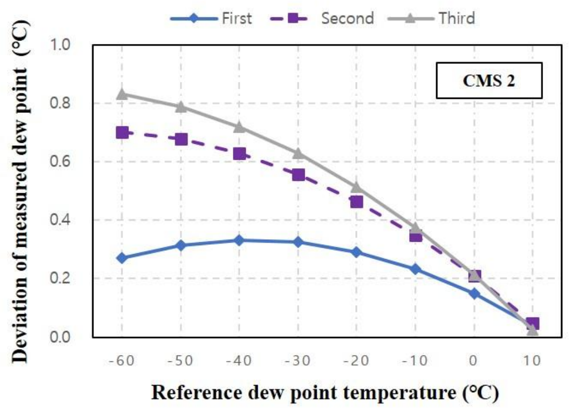
The calibrations for dew point hygrometers of chilled mirror and capacitive aluminum oxide types were performed in order to investigate the series connection order effect on the measured dew point temperatures related to hygrometer type. Basically, the calibration is a comparison procedure of the device under test (DUT) with a traceable reference instrument. The measured dew points between reference standard and the sampling hygrometers were compared at individual reference dew points.

Fig. 5 shows the variation of respective deviation obtained from reference value and measurement results for the chilled mirror sensors and capacitive sensors with changing connection order in series. The patterns for the changing of deviation were incredibly similar regardless of the types of hygrometer. Fig. 5. (a, b, c) present the variation of the measured dew points affected by series connection order for the chilled mirror sensors. When the reference dew point increased, the deviations of the result decreased generally as well as those of sampling hygrometers acted in a similar fashion. The deviations of dew point hygrometer connected directly with calibration gas outlet were the lowest recorded at -60 ℃, the reference dew point. In case of connecting secondly, the deviation increased sharply and in case of connecting thirdly that increased much more, compared with those in the first connection. There were wide deviations each other relatively in the lower reference dew point. The values were presented with approximately 0.4 ℃ on average at -60 ℃, the reference dew point. There is not inconsiderable amount of differences, considering accuracy of chilled mirror sensor used as reference standard in humidity measurement industry. It is expected that the detecting method using water condensation on chilled mirror surface has on effect on flowing reference humid air gas inner connection tube (Fig. 4). This means that the greater the number of chilled mirror sensor connected in series, the higher the risk of measurement error rate.

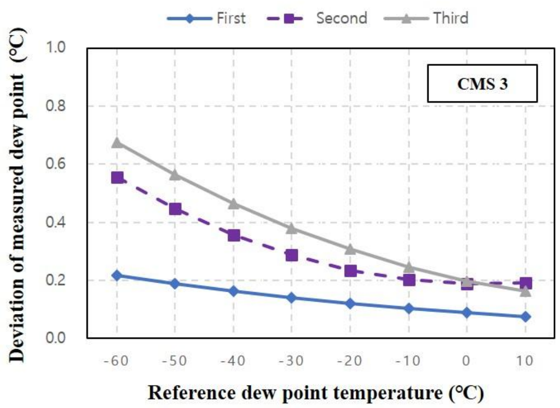
The calibration results (see Fig. 5. (d, e, f)) show that the variations of the measured dew point deviations in capacitive aluminum oxide sensors. The deviations of the results among those sensors were small regardless of connection order of hygrometer contrary to chilled mirror sensor. The differences of deviations of measured dew points as simple numerical comparison among three capacitive sensors were greater than those of chilled mirror sensors, however the deviation caused by the connection order effect was not great, considering accuracy and uncertainty of capacitive aluminum oxide sensor. It is thought that the detecting characteristics by changing sensor's electrical outputs with the amount of water vapor has little influence on the measurement result.



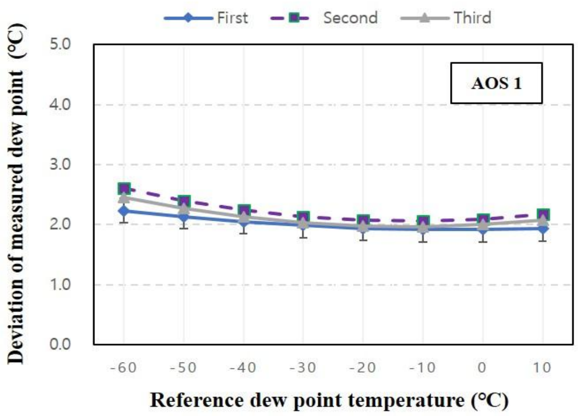
(a) Results of the chilled mirror sensor 1



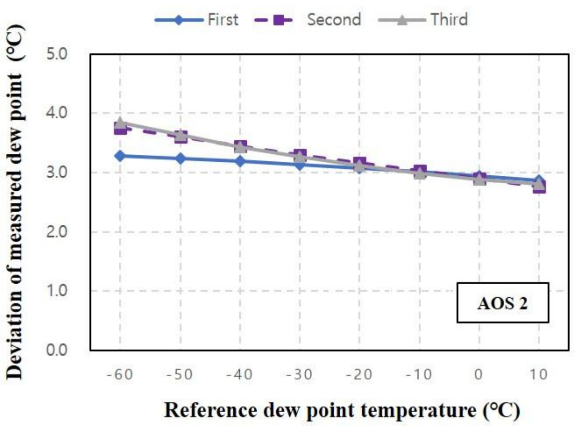
(b) Results of the chilled mirror sensor 2



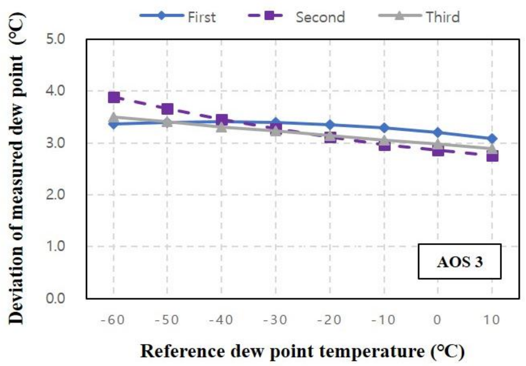
(c) Results of the chilled mirror sensor 3



(d) Results of the aluminum oxide sensor 1



(e) Results of the aluminum oxide sensor 2



(f) Results of the aluminum oxide sensor 3

Figure 5. Variation of deviation values due to different series connection order at each reference dew point

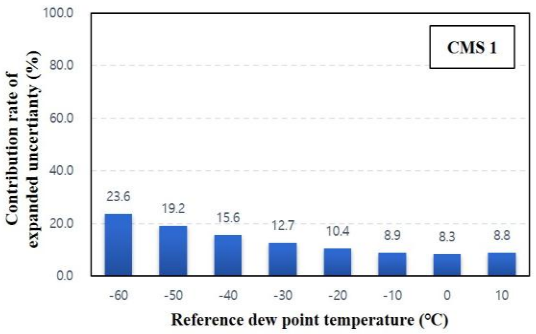
B. Contribution of Series Connection Order Effect on Measurement Uncertainty

The effect of connection order in series of hygrometer on dew point measurement has not yet identified clearly. Therefore, the calibration of dew point hygrometer has been generally performed with connecting several hygrometers in series in many calibration institutes to reduce the calibration time as well as simplify the calibration procedure. In addition, the uncertainty has been evaluated with no consideration for the connection order effect or for compensation of measurement error occurred by it. Therefore, it is necessary that the uncertainty contribution related to the connection order as uncertainty component should be estimated to realize those effect on measurement uncertainty.

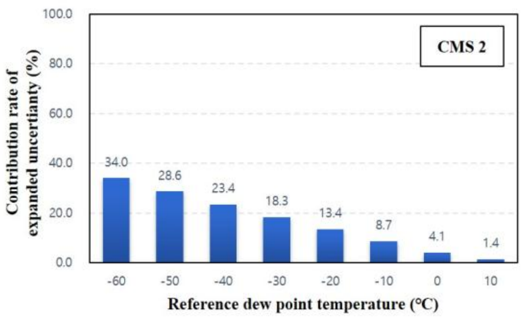
At first, to determine effect of connection order for hygrometers on the measurement uncertainty, expanded uncertainties and uncertainty contributions were estimated for chilled mirror sensors and capacitive aluminum oxide sensors, respectively. The expanded uncertainties (k=2) were estimated with respect to the including connection order effect as an uncertainty source. The method of uncertainty evaluation was based on the international standard EA [15]. The measurement uncertainty was estimated from the experimental standard deviation of the measurement results (type A evaluation) and the calibration uncertainty of reference standard, stability of the reference dew point hygrometer, the stability of the dew point generator, resolution of the sensor and the deviation of the measurement values by fitting formula (type B evaluation). The contribution to the standard uncertainty of the connection order effect was estimated from the deviation calculated in this study using type B evaluation method [15-17]. Also, all standard uncertainties were individual factors independent of each other. Fig. 6 shows the uncertainty contribution rate related to connection order in series between chilled mirror and capacitive aluminum oxide types. The effect of connection order on measurement uncertainty depended on the types of hygrometer and the variations of contribution rates are much different from one another.

Fig. 6. (a, b, c) were calculation results of contribution rate to the standard uncertainty for the chilled mirror sensor effect. As expected and confirmed experimentally,

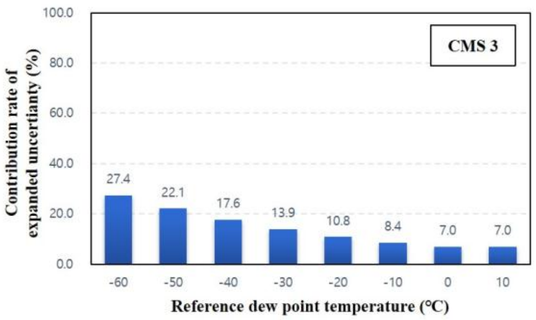
although the numerical values of uncertainty contribution were different, the share of contribution in the expanded uncertainty was the highest at -60 ℃ , reference dew point, on all calibrations of the sensors. As reference dew point increased, the uncertainty contributions decreased on all occasions. In particular, the share for contribution related to connection order effect was changed significantly until 0 ℃ . The contributions to the standard uncertainty related to connection order account for above 20 % of expanded uncertainties on all of the calibrations.



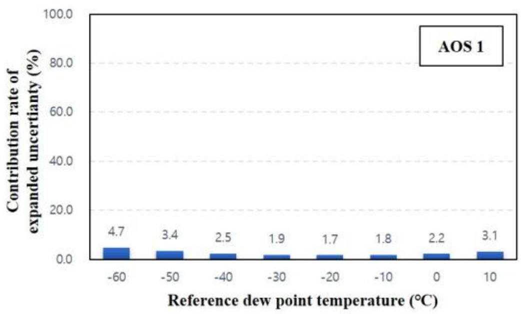
(a) Contribution of the chilled mirror sensor 1



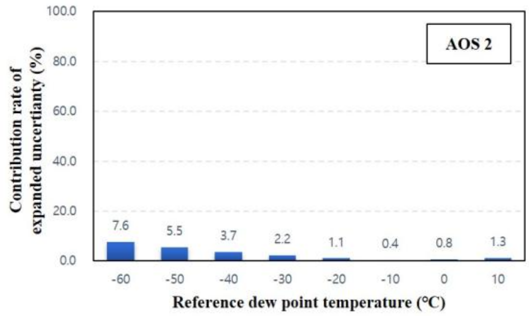
(b) Contribution of the chilled mirror sensor 2



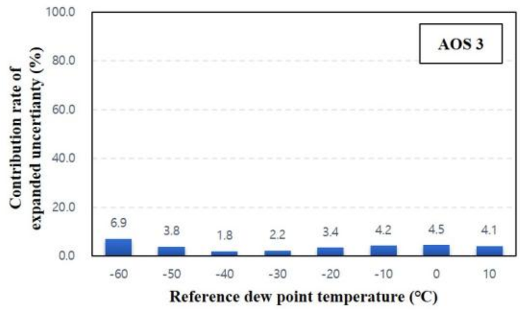
(c) Contribution of the chilled mirror sensor 3



(d) Contribution of the aluminum oxide sensor 1



(e) Contribution of the aluminum oxide sensor 2



(f) Contribution of the aluminum oxide sensor 3

Figure 6. Uncertainty contributions related to the effect of series connection order due to hygrometer types

In other word, from the contribution rates evaluated (see Fig. 6. (a, b, c)), the expanded uncertainty for chilled mirror sensor was clearly dominated by the effect of the uncertainty due to series connection order at below 0 ℃, reference dew point temperature. It is expected that the lower the reference temperature, the higher the series connection order effect of chilled mirror sensor on measurement uncertainty as well as the uncertainty contribution is larger than the others relatively.

Fig. 6. (d, e, f) shows contribution rate to the standard uncertainty for different three capacitive aluminum oxide sensor. There were few or no change in the contribution rates due to reference dew points on all occasions. Also, the ratio of uncertainty contribution related to series connection order was low relatively with below approximately 5 % on average. It is thought that the uncertainty contribution rate is low relatively owing to the higher expanded uncertainty of capacitive aluminum oxide sensor with detecting characteristics. We predict that uncertainty component related to connection order has little effect on the expanded uncertainty regardless of reference dew point temperature.

IV. Conclusion

In this work, the response characteristics of dew point hygrometer with chilled mirror type and aluminum oxide type were evaluated by calibration and numerical analysis. To analyze the response characteristics in detail, the effect of connection order in series on the measured dew point temperature and the ratio of uncertainty contribution to the standard uncertainty in the expanded uncertainty were investigated. The analysis was based on mainly on the calibration results with two different types of hygrometers between -60 ℃ and 10 ℃, reference dew point temperature.

When the reference dew point decreased, the deviations of measured dew point temperature of chilled mirror hygrometer increased significantly. The deviations in cases of hygrometers connected directly with calibration gas outlet were the lowest recorded in the entire ranges. The deviations of the results among aluminum oxide sensors were small regardless of series connection order of hygrometer contrary to chilled mirror sensor. It is thought that those differences were caused by the respective detecting characteristics of chilled mirror and capacitive aluminum oxide sensor. Thus, the connection order in series had a great effect on the calibration result of the chilled mirror dew point sensor.

For evaluating uncertainty contribution on the expanded uncertainties (k=2) estimated using the dew point hygrometer, the ratio of uncertainty contribution on expanded uncertainty due to the types of hygrometer were calculated in individual reference dew point temperatures. The effect of the uncertainty due to series connection order was great at above 0 ℃, reference dew point temperature. In other word, it is expected that expanded uncertainty for chilled mirror sensor was clearly dominated by uncertainty component related to series connection order. The ratio of uncertainty contribution related to series connection order of capacitive aluminum oxide sensor, meanwhile, was noticeably low with below 5 % on average. We predict that uncertainty component related to connection order has little effect on the expanded uncertainty in the calibration of capacitive sensor regardless of reference dew point temperature.

We realized that the effect of series connection order of hygrometer is different remarkably according to response characteristics of hygrometers and reference dew point temperature. It is necessary to understand the contribution to the standard uncertainty for connection order effect in respect of variance of measurement uncertainty in the whole calibration procedure. Also, it is desired that the proper organization of connection order should be selected to obtain the reliable calibration result as well as to reduce measurement uncertainties at each reference dew point temperature according to the response characteristics of hygrometers.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

The author conducted the research, experiment and wrote the paper.

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