Response Characteristics of Dew Point Sensor with Aluminum Oxide by means of Correlation between Purging Rate and Tube Length

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Abstract—**The purpose of this paper is to study in more detail response characteristics by means of correlation and interaction between purging rate and tube length with different parameters to establish proper environment parameters in calibration procedure of the dew point sensor (DPS). The effect of purging rate and tube length condition on the measured dew point temperature and correlation between them were investigated by analyzing variation of measurement results due to various reference dew points with capacitive dew point sensor with aluminum oxide during a time period of over a year. The measurement is carried out to analyze the variation on measured dew point temperatures for sampling dew point sensor (DPS) due to various purging rate from 5 hours to 120 hours and tube length condition from 1000 mm to 6500 mm by using calibrated standard chilled mirror hygrometer. The correlation and interaction between purging rate and tube length condition on the measurement accuracy and reliability were analyzed with measurement results for reference dew point temperatures from -60 ℃ to 10 ℃. The measurement was conducted according to standard calibration procedure of Korea Testing Laboratory which assures suitability and traceable results. It is also based on international standards.**

Index Terms—**capacitive dew point sensor, dew point temperature, purging rate, tube length, measurement**

I. Introduction

Dew point temperature is a measure of how much water vapor there is in a gas. It is temperature to which air must be cooled to reach saturation. A higher dew point indicates more moisture present in the air. Therefore, the accurate and precise measurement of the dew point temperature has become increasingly important in the package process of micro-electric, medicine and medical supplies, the quality of foodstuffs, the growth of microorganisms [1], [2].

There are two types of reference dew point sensors (DPS) with the chilled mirror and capacitive-aluminum oxide types widely used in commercial, industrial and weather stations to measure water vapor content of a gas. The chilled mirror sensor is a device based on an optical technique for the measurement of dew point temperature. It is used a calibration standard to obtain accurate and reliable measurement results [1], [2]. The capacitive-aluminum oxide sensor uses a moisture sensor, aluminum oxide, which changes its electrical output with the amount of water vapor to which it is exposed [3]. It is used extensively in dew point measurement.

The important factors to obtain reliable measurement results of the DPS are accurate and precise reference instruments as well as optimal environment conditions such as residual moisture, gas flow rate, leaking rate in tubing, pressure and material. In our previous study [4], [5], the effects of purging rate and tube length on the measured dew point temperature were investigated respectably by experiment and numerical analysis. It is necessary to analyze associative relation between purging rate and tube length effect in respect of suitable measurement procedure due to various environment conditions.

The purpose of this paper is to study in more detail response characteristics by means of correlation and interaction between purging rate and tube length with different parameter to establish proper environment parameters in calibration procedure of the DPS with aluminum oxide. We focus on the measurement and the control of purging rate and tube length. The correlation between purging rate and tube length condition on the measurement accuracy and reliability was analyzed with measurement results for reference dew point temperatures from -60 ℃ to 10 ℃.

II. Experimental Setup

The correlation and interaction between purging rate and tube length condition were investigated by analyzing variation of measurement results due to various reference dew points with capacitive dew point sensor during a time period of over a year. Fig. 1 shows a schematic of

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the experimental setup used in the present study. The measurement system of dew point temperature was initiated with setting up a dew point generator kept to a constant temperature of 35 ℃. Dew point generator, michell DG-4, was used to supply air gas with well-controlled reference dew point temperatures. A chilled mirror hygrometer was used as reference standard to measure dew point temperature of air passed through tubes in various environmental conditions. The sampling DPS of capacitive type and reference standard, hilled mirror hygrometer were connected with the gas outlet of dew point generator using tubing, respectively. The connected tubes were made of stainless steel with the inner diameter of 4 mm. Two flow meters were used to control the gas flow rate for the sampling dew point sensor (DPS) and reference standard chilled mirror hygrometer respectively. This flow was divided into two flows. One flow was introduced to reference standard. The other was introduced to sampling DPS. The full scales of two flow meters were 5 L/min and 1 L/min. The flow rates to reference standard hygrometer and to sampling DPSs were controlled with 0.5 L/min and 3 L/min respectively in all the tests.

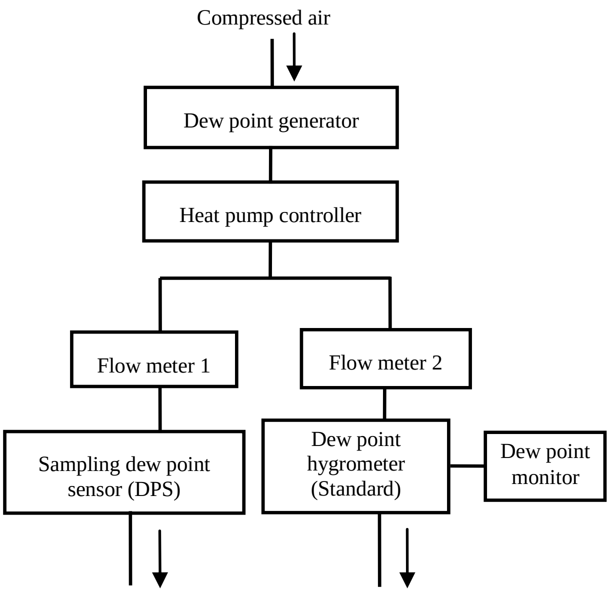


Figure 1. Block diagram of the measurement setup including the dew point generator, dew point hygrometer as a reference standard and sampling dew point sensor (DPS)

Basically, the sensor body, tubes, valves and flow meters are heated and their temperature must always be higher than the dew point temperature, if not condensation will occur in the sensor's measurement space and internal sample system tubes [1], [6]. This means that before changing to wetter dew points, the sensor body temperature must be raised and allowed to stabilize at the new temperature. Therefore, the working space of the system was slightly heated over approximately 20 ℃ rather than reference dew point temperatures from -60 ℃ to 10 ℃ to avoid any condensation in it while measuring them. The temperature of the sensor body was maintained at 20 ℃ or more by monitoring the temperature with a platinum resistance thermometer (PRT). Ambient temperature and relative humidity were measured with a PRT and polymer thin film hygrometer calibrated at KTL, respectively. A digital barometer was used to determine the pressure difference between the generator and reference dew point hygrometer.

A leak in measurement systems including tubing or sample sensor's working space causes a direct effect on the measurement result. In particular, if the gas pressure in the tube is lower than the ambient air pressure, a leak allows ambient air to enter the sampling tube due to the pressure difference [7]-[9]. To prevent the errors caused by leaks in the entire measurement system, a simple leak test was performed by closing the air flow tube and monitoring air flow meter.

III. Environmental Variable Controls

When considering gas flow and residual moisture in the tubing, purging rate and tube length were the most important factors to obtain reliable measurement results. The effect of interaction between purging rate and tube length condition on the measurement of DPS was not identified precisely. Therefore, the work in this article was mainly focused on correlation between purging rate and tube length with different parameters.

The measurement was performed for the sampling DPS under various purging rate and tube length condition with different parameters. The purging rate is mainly dependent upon the duration of purge. To set up this condition, the whole measurement system was kept in the state of purging for 5 hours, 20 hours, 70 hours, and 120 hours. Also, the measurement is carried out under tube length with 1000 mm, 4000 mm and 6500 mm under various purging conditions. The dew point temperatures were measured in the range from -60 ℃ to 10 ℃ with the interval of 10 ℃.

In order to estimate the correlation and interaction between purging rate and tube length condtion as well as establish proper enviroment parameters in calibration procedure of the DPS, the response characteristics due to various purging and tubing conditons were analyzed. The measurement was conducted according to standard calibration procedure of Korea Testing Laboratory which assures suitability and traceable results. It is also based on international standards [10], [11].

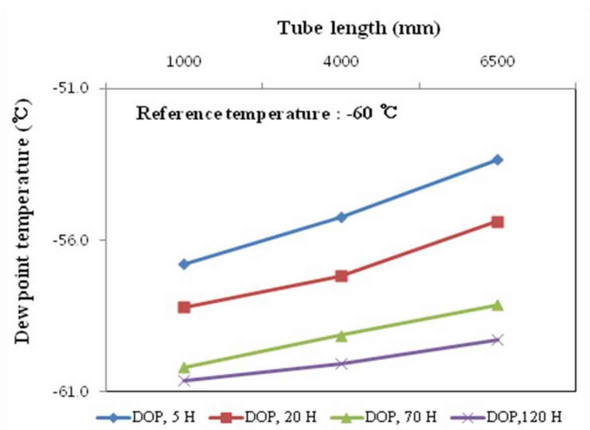
IV. Results and Discussion

A. *Effect of Purging Rate and Tube Length on the Measured Dew Point Temperatures*

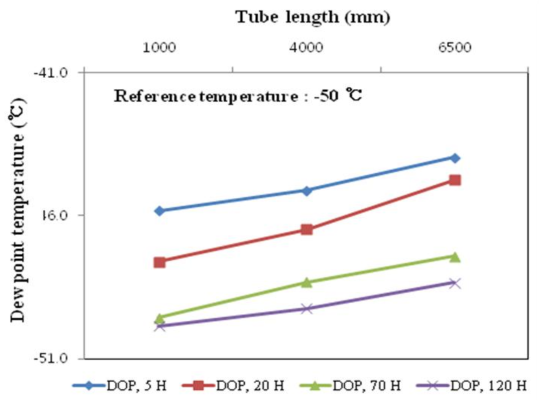
Experimental tests were carried out in order to conduct a study on the effect of purging rate and tube length on the measurement results. Total three outputs with a measurement of three times were recorded for each reference dew point temperature, in the range from -60 ℃ to 10 ℃ in 10 ℃ steps. Fig. 2 shows the variation of measurement results affected by duration of purge and tube length at each reference dew point. The measurements (see Fig. 2 (a, b, c)) show that the variations of measurement values at the reference dew point, -60 ℃ were relatively wider than them at the reference dew point, -50 ℃ and -40 ℃. When the reference dew point decreased, the variations of measurement values tend to increase generally regardless of purging rate and tube length condition in all occasions. However, the variation rate was different depended on correlation of purging rate and tube length condition. This trend appeared at the range of below reference dew point, -10 ℃ throughout all measurements. This means that the effect of the residual moisture caused error of the measurement values was minimized through suitable proper purge process and tube length condition according to the reference dew point temperatures.

In particular, when purging process was insufficient relatively below 20 hours, the variation of measurement results increased sharply according to the tube length condition. The tube length condition was considered as an important factor in a state of inadequate purging process. On the other hand, the more duration of purge was long over 70 hours sufficiently, the more difference rate of measured dew point temperatures decreased relatively, although the tube increased in length.

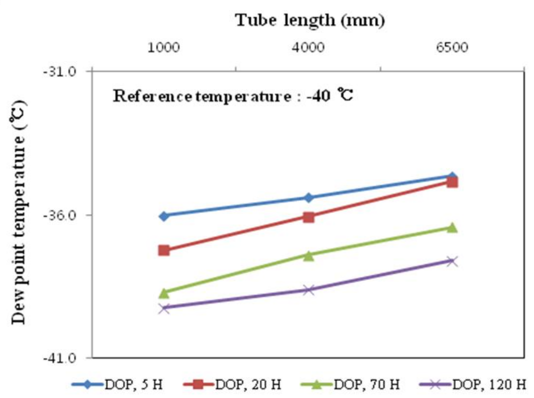
It can be noted in Fig. 2 ((d), (e)) that the variation of measurement values increased modestly with similar trend as a tube increased in length. The maximum differences of the results at -30 ℃ and -20 ℃, the reference dew points, were approximately 3.2 ℃ and 2.7 ℃ under 6500 mm, tube length condition. As it was expected, the deviation of measurement results in the range approximately over -10 ℃, reference dew point, (see Fig. 2 (f)) decreased as tube length decreased under all of the purging conditions. Moreover, the measurement results (see Fig. 2 (g), (h)) were almost the same under short tube in length, 1000 mm, relatively under reference dew point of over 10 ℃. It shows that maximum difference of the results due to various purging rate was less than 0.9 ℃ under the condition of tube in equal length.



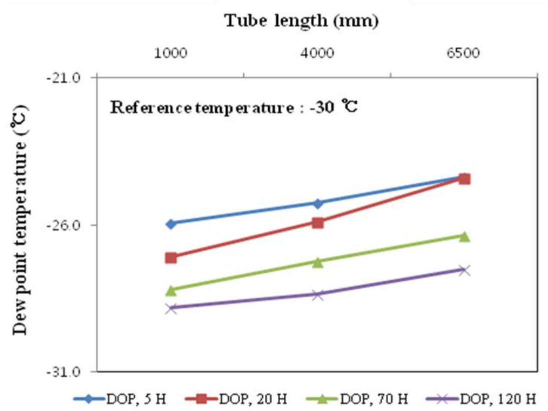
(a) At the reference dew point, -60 ℃



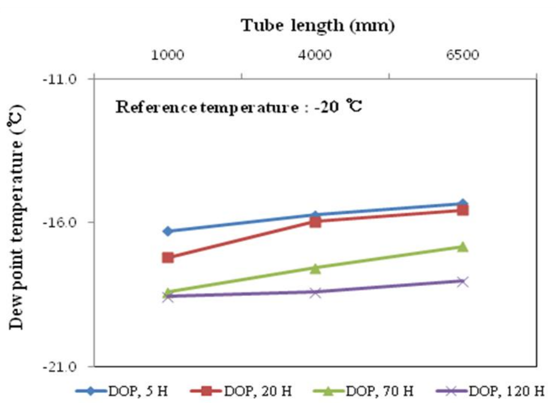
(b) At the reference dew point, -50 ℃



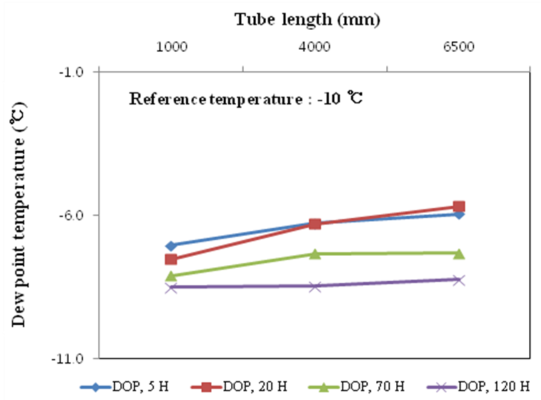
(c) At the reference dew point, -40 ℃



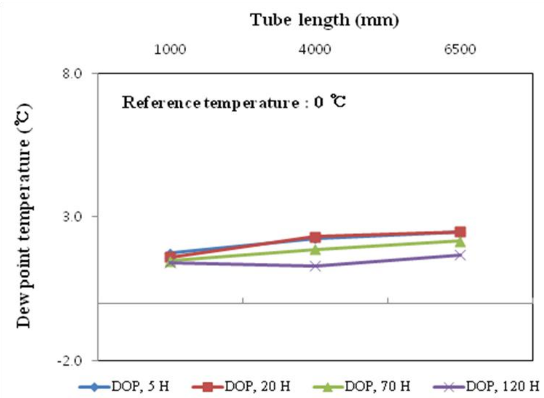
(d) At the reference dew point, -30 ℃



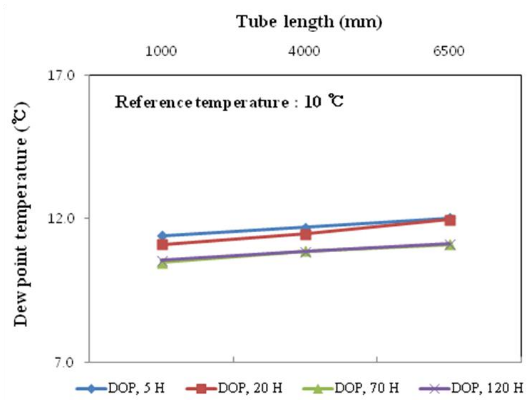
(e) At the reference dew point, -20 ℃



(f) At the reference dew point, -10 ℃



(g) At the reference dew point, 0 ℃



(h) At the reference dew point, 10 ℃

Figure 2. Variation of the measurement values

B. *Analysis of Correlation and Interaction between Purging Rate and Tube Length Effect*

The differences between maximum and minimum dew points measured in various purging rate with respect to each tube in equal length are shown in Fig. 3. The differences of measurement values due to various purging rate were estimated differently. In particular, the difference was more reduced effectively when the reference dew point increased in condition of tube length, 6500 mm. By contrast, the difference reduced gradually in condition of tube length, 1000 mm due to the reference dew points.

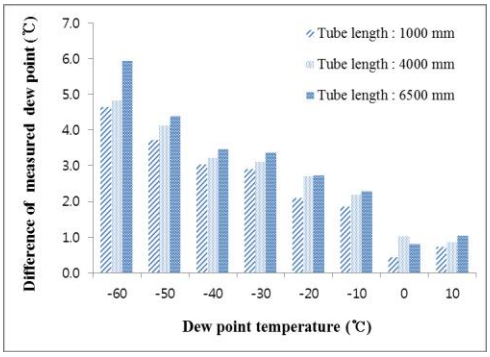


Figure 3. The results of the comparison of differences between maximum and minimum values of the measured dew points due to various purging rate

Fig. 4 presents the differences of measured dew points due to the tubes with various lengths and reference dew point temperatures. It can be concluded that the purging rate and tube length seem to have much effect on the response characteristics in the lower reference dew point. It was expected that the residual moisture in the whole test unit leads to a maximum deviation in dew point reading up to approximately 6 ℃ and 3.5 ℃ by means of purging rate and tube length effect respectively. In other words, the absorption of residual moisture in the entire tube and test unit does have significant negative impact on the response characteristics.

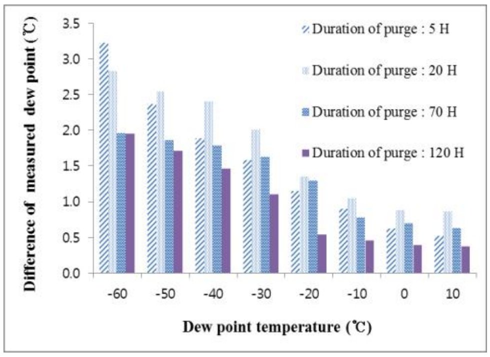


Figure 4. The results of the comparison of differences between maximum and minimum values of the measured dew points due to tubes in various lengths

The maximum difference of measured dew point temperature due to various purging rate was more than approximately 5.9 % in condition of tube in length, 6500 mm and reference dew point, -60 ℃. Also, when the tube length increased, the deviation of measured dew point temperatures increased by 3.2 % under the insufficient duration of purge, 5 hours. Moreover, the deviation of measurement values increased three times by means of tube length effect in the range of below -10 ℃, reference dew point temperature. This means that the lower reference dew point, the more variation rates of measured dew points was strongly dependent on purging rate as compared with tube length condition. When purging process could not be performed properly due to the characteristic of measurement systems, tube length factor has a significant effect relatively. Also, purging rate and tube length condition had little effect on the response characteristics in the range approximately over -10 ℃ on all occasions.

V. Conclusions

In this work, the effect of purging rate and tube length condition on the measured dew point temperature and correlation between them to establish suitable environmental measurement condition were studied by experiment and numerical analysis. They were conducted with the measurement results made with capacitive DPS and reference standard, chilled mirror hygrometer under four purging and three tubing conditions from -60 ℃ and 10 ℃, reference dew point temperature. By analyzing the accuracy and changing trend on the measurement results of DPS corresponding to the purging and tubing condition, we assessed how residual moisture can affect reliability of the measured dew point temperature.

When the reference dew point temperature decreased, the variation of measurement values tend to increase generally on all occasions, even though the variation rates depend on purging and tube length conditions. The purging and tube length conditions must be as a considerably important factor in a state of below reference dew point of -10 ℃. However, purging rate and tube length had little effect on the response characteristics in the range over approximately -10 ℃ in all the tests. It is expected that residual moisture in the whole measurement system including DPS had directly effect on the accuracy and precision of measurement results in the low dew point temperature. It can be dried and removed as much as possible before measuring DPS by regulating suitably purging process and selecting tube length to minimize effect of residual moisture in the whole system.

The lower reference dew point, the more variation rate of measured dew point was strongly dependent on purging rate as compared with tube length condition. However, when purging process could not be performed properly depending on the characteristic of measurement systems, tube length factor play an important role in the measurement relatively. In conclusion, purging process and tube length effect are closely related to each other as well as contributions to the reliable results due to the range of reference dew point. Thus, it is necessary to understand the response characteristics of DPS and test instrument by means of the correlation and interaction between purging process and tube length effect due to the range of reference dew point in measurement system built in each institute. Measurement of DPS should be performed by selecting purging process and tube length condition efficiently due to reference dew point temperature in the whole measurement system. Also, it is desired that effective measurement method considering purging rate and tube length effect should be established to improve the reliability and quality of measurement results.

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