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CRADA Final Report
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MOISTURE SENSOR FOR SULFUR NEXAFLUORDE (SF6)-FILLED CIRCUIT BREAKERS

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ORNL/Doble/Kahn CRADA - Final Report

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Abstract

Measurements at ORNL were made on the Kahn moisture sensor which Doble Engineering wants to evaluate for use in SF_6 circuit breakers. Test conducted at ORNL indicate that vacuum conditions, as might be found in SF_6 circuit breakers prior to filling with SF_6, could lead to significant changes in calibration, resulting in erroneous readings of moisture content. Similar effects might also be observed in cases where SF_6 byproducts are present, due the reactivity of some of these byproducts with water.

Objectives

The objectives of this project were to evaluate the use of the Kahn moisture sensor for use in high voltage SF_6 circuit breakers and discuss the reliability of these sensors for its intended use.

Benefits to DOE

ORNL's experience and expertise in SF_6 and its arc byproducts was applied to the potential use of moisture sensors on SF_6-filled high voltage equipment for the safe and effective use of this type of equipment in the power grid.

Technical Role of the CRADA parties

Doble Engineering: Provide technical information on the application of moisture sensors in the environment of circuit breakers having high voltage, vacuum and SF_6 byproducts.
Kahn Instruments: Provide the moisture sensors for testing at ORNL.
ORNL: Conducts all the laboratory tests of the Kahn moisture sensors. Technical discussion of these tests follow.

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1. Initial Evaluation

Problems were encountered in the calibration of the Kahn moisture sensor (Sensor #1) which we received originally. Through discussions with Mr. Bob Hamburger at Kahn, it was suggested that Sensor #1 experienced a change in calibration due to exposure to vacuum conditions during testing in my lab. The sensor was returned to Kahn for re-calibration where it was confirmed that the calibration had significantly changed. Mr. Hamburger believes that the change in calibration was due to removal of water from the bulk ceramic material, a problem which he said should not occur if proper manufacturing conditions are employed in which water molecules are fixed chemically to the interstitial sites of the bulk material. Mr. Hamburger felt that the manufacturing problem had been corrected for the newer sensors and was interested in seeing the results of my tests on a new sensor. Kahn therefore sent me another sensor (Sensor #2) to test. This progress report documents the results of tests conducted on Sensor #2.

2. Test set up

The test cell was a Varian cross made of stainless steel with 2 3/4" conflat flanges at each of the four ports. The volume of the cell was approximately 300 cm^3. Connected to each port were a gas inlet/pump out line, a 0-10 Torr MKS Baratron pressure transducer (with $1x10^{-3}$ Torr resolution), the Kahn moisture sensor (Sensor #2), and a glass/stainless steel cell containing liquid water. A butterfly valve between the water cell and test cell permitted isolation of the water cell. Valves were also located between the pressure sensor and test cell and between the vacuum/gas inlet line and the test cell. Prior to measurement of the water vapor pressure and dew point reading the test cell was evacuated using a vacuum pump to a pressure of approximately $1x10^{-3}$ Torr. With the valve to the pumping system closed the leak rate was found to be less than $4x10^{-3}$ Torr per hour.

For most of the tests the starting test cell conditions were dryer than -80° C as indicated by Sensor #2. Two methods, "increasing" and "decreasing", were employed to determine the accuracy of the Sensor #2 response. In the "increasing" method 3-5 microliters of distilled water was injected into the gas line via a septum and using a gas tight syringe. Water vapor was then metered into the test cell and the water vapor pressure and Sensor #2 outputs were monitored with time. Output of both pressure and dew point sensors were recorded by two digital voltmeters equipped with RS-232 connections to permit the data to be stored on computer. After allowing time for both sensors to reach a plateau, additional water vapor was metered into the test cell. In the "decreasing" method a large amount of water vapor (about 10 Torr) was initially admitted into the test cell. After equilibration with sensors/walls, the water vapor pressure was decreased incrementally and monitored with time.

The water vapor pressure data was converted to dew point using a curve fit (Figure 1) and interpolation of the water vapor pressure/dew point data contained in the CRC Handbook.' A test of the accuracy and reliability of the pressure reading of water vapor was made by measuring the water vapor pressure of liquid water at 0° C. The dew point as determined by the pressure sensor was +0.4° C. The pressure gauge was found to be linear over the entire range and "zeroed" to within 0.002 Torr. In all the measurements sufficient time had to be allowed for the water vapor and the two sensors to reach a constant value. This is illustrated in Figure 2 which shows the time dependencies of the pressure sensor and Sensor #2 outputs for the initial admission of about 1 Torr of water vapor into the evacuated (< 0.001 Torr) test cell at a time near t=0s. The pressure sensor data was converted to dew point. The pressure sensor recorded an initial steep rise to about -15°C followed by an approximately exponential decay to an asymptotic value of -25°C. The output of the Kahn sensor rose at a much slower rate followed by a leveling off to -35°C. Because of the slower response of the Kahn sensor the dew point reading does not reflect the initial moisture condition in which the water vapor content decreases as water is adsorbed on the walls of the test cell. A comparison of the two sensors' response is shown in Figure 3 in terms of the percentage of each sensor's asymptotic value. From this it can be seen that it takes on the order of about 1000-1500s (~15-25 min) for the two sensors to be within ~ 5% of the asymptotic value. Generally, all determinations of dew point from both sensors were made at times greater than 15 min and typically 30 min after each change in water vapor content.

3. Test Results

Five independent sets of data were taken on five different days. Two sets were taken using the "decreasing" method and three sets were taken using the "increasing" method. The data are shown in Figure 4, showing the dew point derived from the pressure sensor plotted against the Kahn sensor #2 reading. All the data points lie above the solid line which would indicate a perfect match between the two sensors. The error in the sensor #2 dew point reading, is defined as

$$DP_{error} = DP_{press} - DP_{\#2}$$

where DP_{press} is the dew point derived from the vapor pressure reading and $DP_{\#2}$ is the Kahn sensor #2 dew point reading. The dew point error is plotted in Figure 5. Assuming that DP_{press} is correct then the Kahn sensor is in error by the amount indicated by DP_{error}, that is , the Kahn sensor indicates a dew point too low by an amount equal to DP_{error}. The error varies from as much as 15°C (around -50°C and 0°C) , to a minimum of about 6°C (at -20°C). All five sets of data are consistent with each other indicating no systematic change in calibration from one set of measurements to another. As mentioned earlier it is believed that the calibration is due to moisture removal from the sensor material while under vacuum conditions. To check for possible recovery of the sensor after exposure to ambient room air (saturated with water vapor from liquid water at room temperature), two additional sets of data were taken and compared to the previous data (Figure 6). One set of data was for overnight exposure (about 12 hours) and the other set was over-the-weekend exposure (about 40 hours). Both sets of data indicate slightly higher error, but are otherwise consistent in dew point dependence with that of the pre-exposure conditions.

4. Conclusions

The calibration of Sensor #2 was found to be off (too low) by 6-15°C when compared to direct water vapor pressure measurements. Loss of water molecules from interstitial sites, during evacuation and exposure to vacuum conditions are believed to be the cause. Once changed, the calibration appears to be relatively constant and unaffected by exposure to high moisture content conditions for 12-40 hours. It is not known from these data how long the initial exposure to vacuum conditions is needed to cause the calibration change that I observed. Tests on a third sensor is indicated to determine when the calibration change occurs. Influence of vacuum on sensor response is considered to be important for SF_6-filled high voltage equipment applications since these devices are typically evacuated to below 0.1 Torr prior to filling with SF_6. One additional concern is that if exposure to vacuum conditions results in removal of water vapor from the sensor material, changing its calibration, then exposure to SF_6 byproducts such as SF_4 or SOF_4 which hydrolyze may have a similar effect on the sensor's response. Future tests exposing moisture sensors to SF_6 arc byproducts are recommended to address this potential problem.

Figure Captions

Fig 1: Vapor pressure vs dew point

Fig 2: Time dependence of pressure sensor and Sensor 2

Fig 3: Comparison of 2 sensor responses

Fig 4: 5 data sets

Fig 5: Dew point error

Fig 6: 2 more data sets following exposure to air

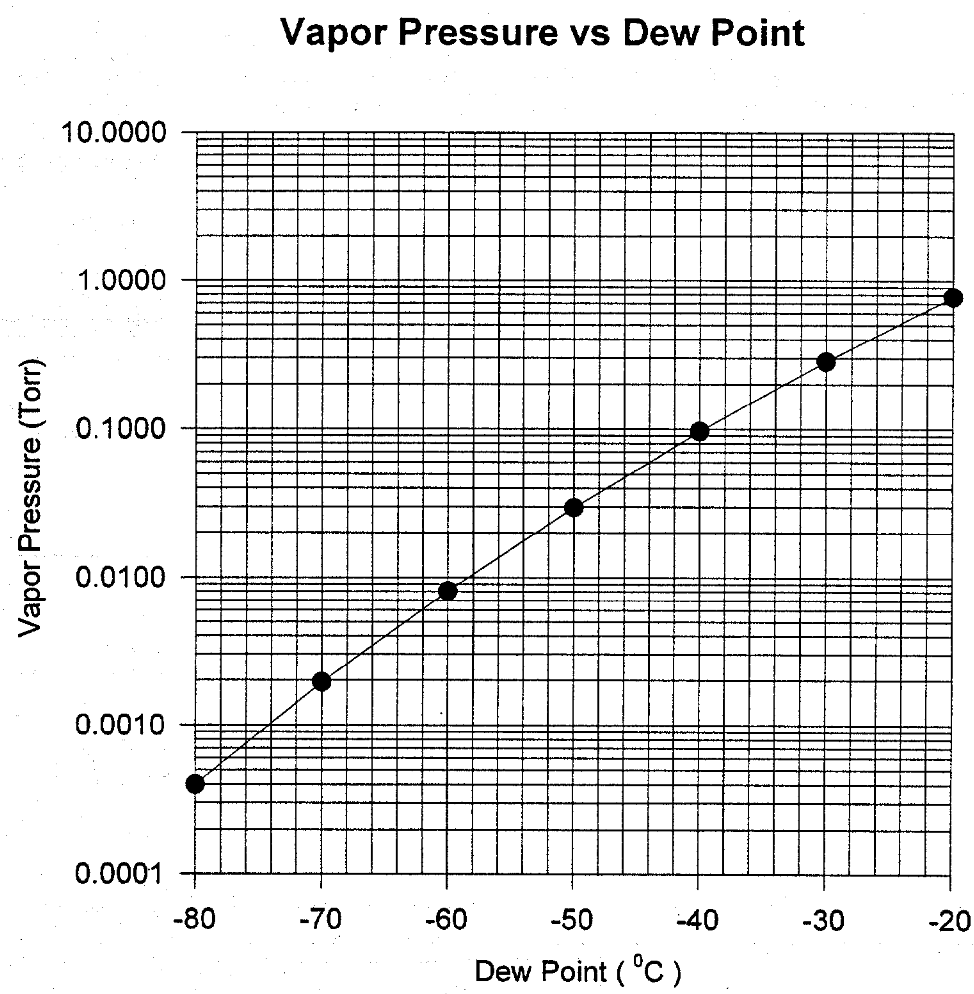

Vapor Pressure vs Dew Point
10.0000
1.0000
0.1000
0.0100
0.0010
0.0001
Vapor Pressure (Torr)
-80
-70
-60
-50
-40
-30
-20
Dew Point (^{0}C)

Figure 1

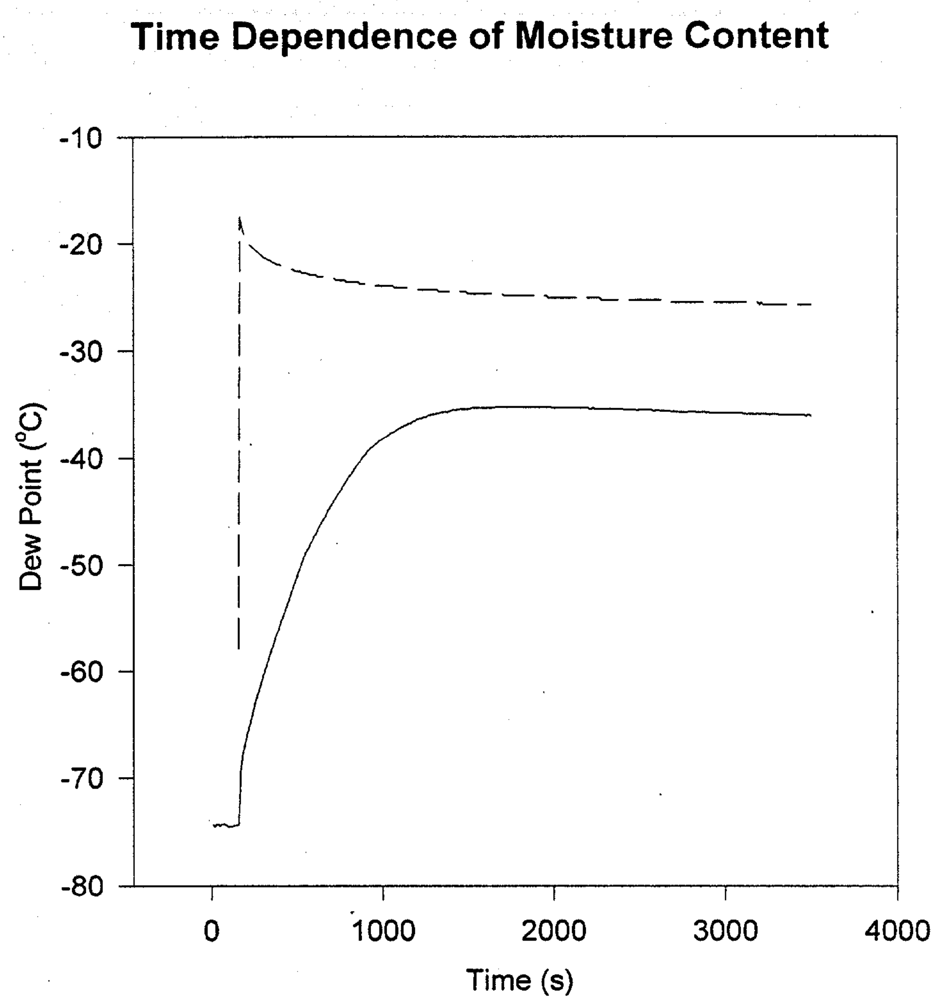

Time Dependence of Moisture Content
-10
-20
-30
-40
-50
-60
-70
-80
Dew Point (°C)
0
1000
2000
3000
4000
Time (s)

Figure 2

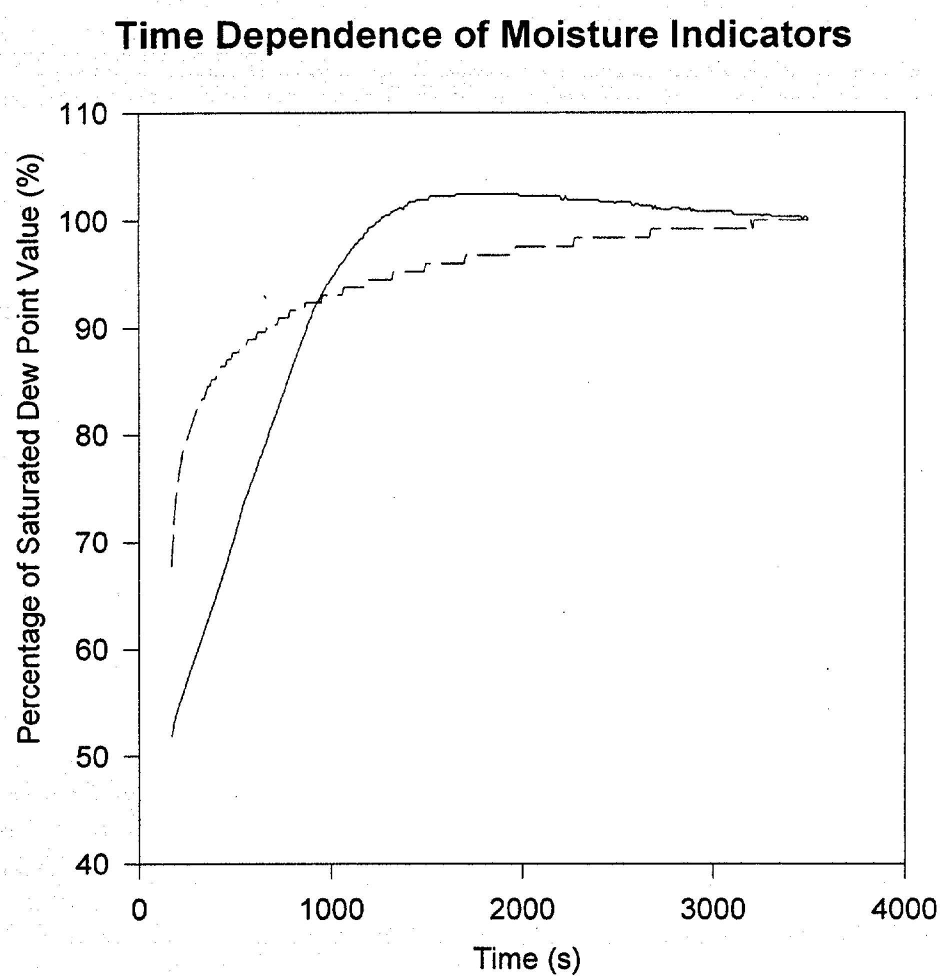

Time Dependence of Moisture Indicators
Percentage of Saturated Dew Point Value (%)
110
100
90
80
70
60
50
40
0
1000
2000
3000
4000
Time (s)

Figure 3

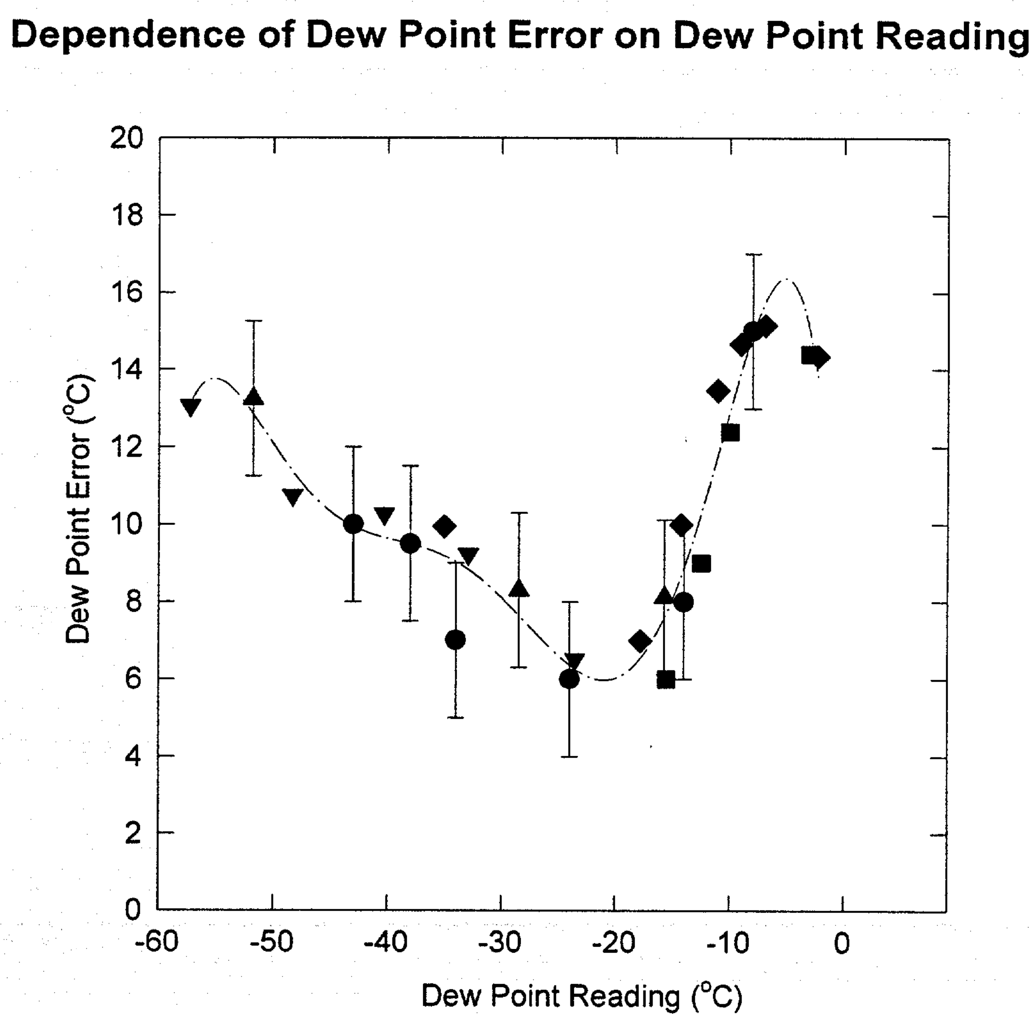
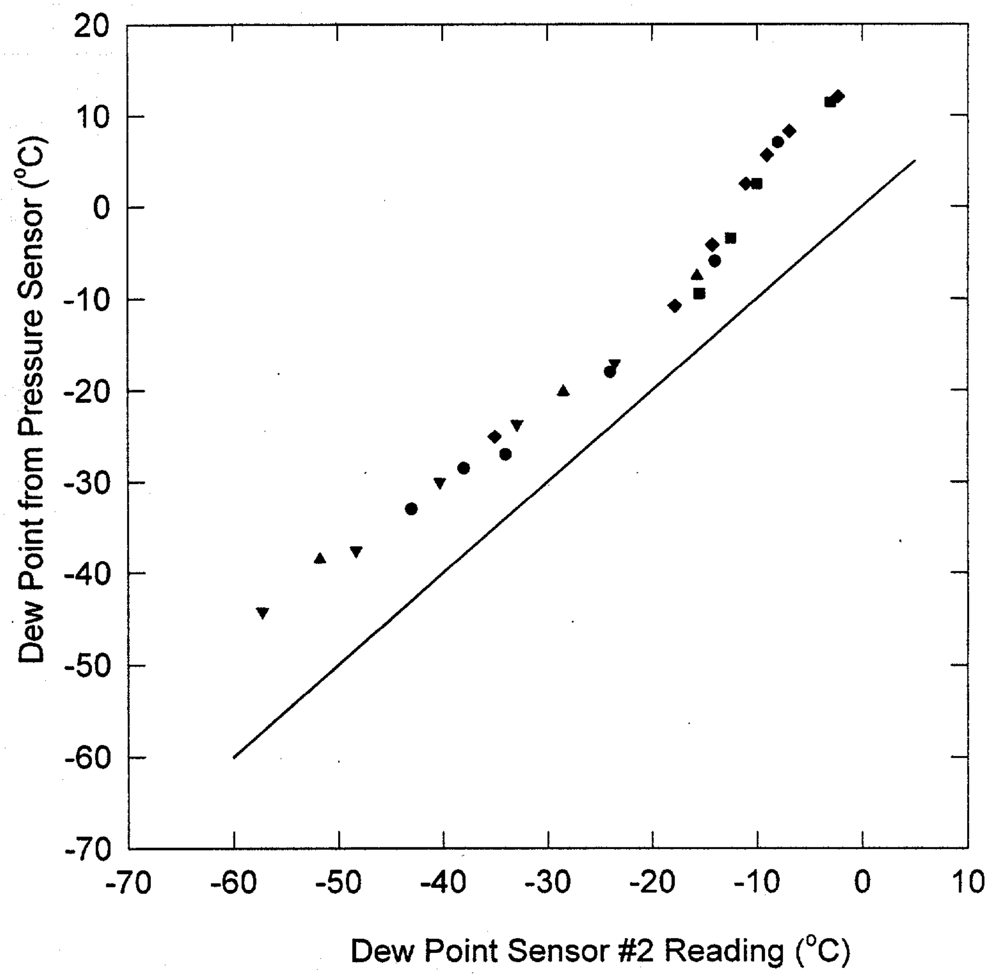

Dependence of Dew Point Error on Dew Point Reading
Dew Point Error (°C)
Dew Point Reading (°C)
0
2
4
6
8
10
12
14
16
18
20
-60
-50
-40
-30
-20
-10
0

Figure 4



20
10
0
-10
-20
-30
-40
-50
-60
-70
-70
-60
-50
-40
-30
-20
-10
0
10
Dew Point from Pressure Sensor (°C)
Dew Point Sensor #2 Reading (°C)

Figure 5

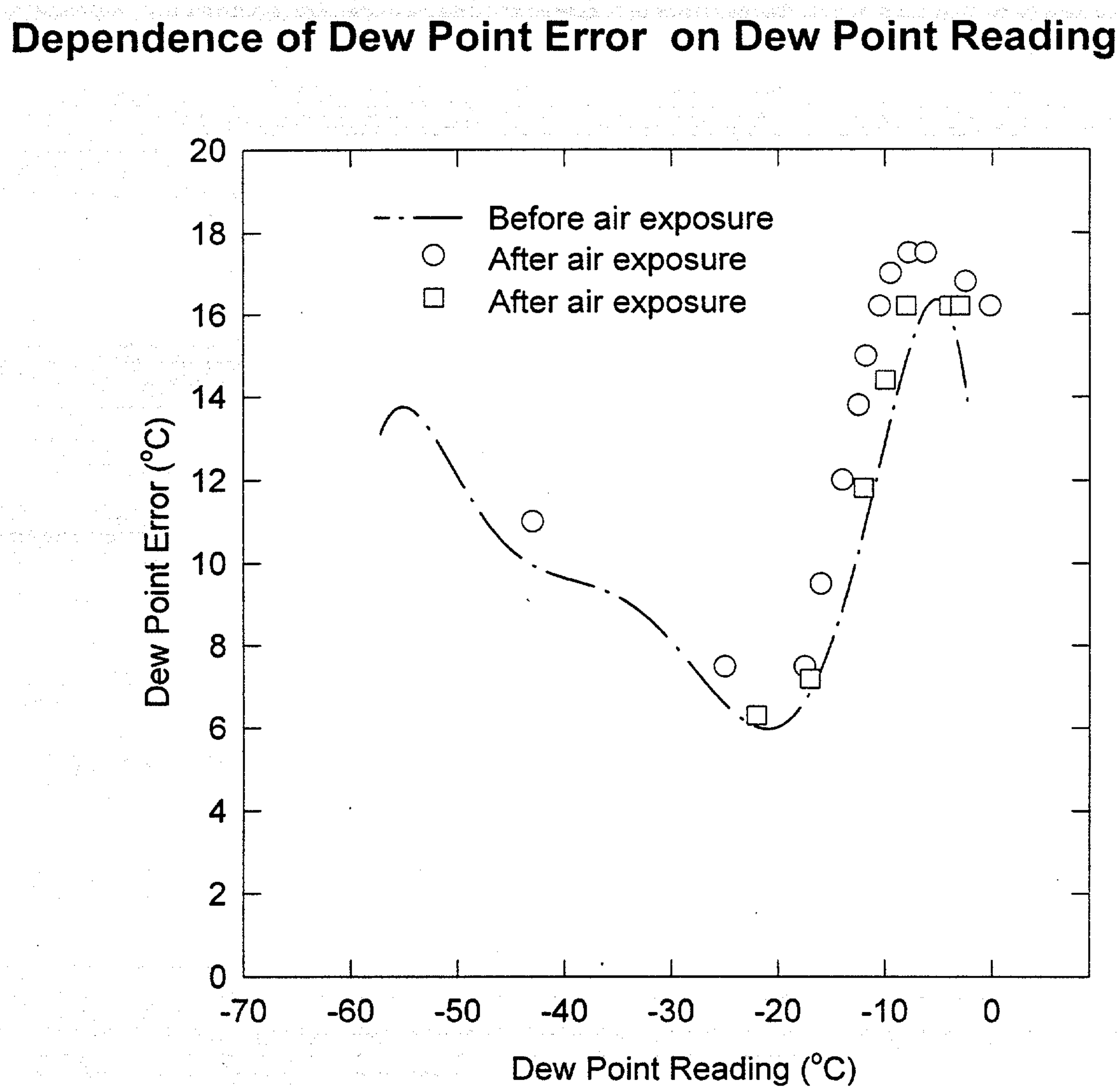

Dependence of Dew Point Error on Dew Point Reading
Before air exposure
After air exposure
After air exposure
Dew Point Error (°C)
Dew Point Reading (°C)
20
18
16
14
12
10
8
6
4
2
0
-70
-60
-50
-40
-30
-20
-10
0

Figure 6

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