NOTES AND CORRESPONDENCE

A Test of Commercial Humidity Sensors for Use at Automatic Weather Stations

SARA H. MULLER AND PIETER J. BEEKMAN

Royal Netherlands Meteorological Institute (KNMI), De Bilt, The Netherlands

17 July 1986 and 25 March 1987

ABSTRACT

Laboratory tests of eight different sensors based on five different principles were performed at relative humidities between 20% and 100% and temperatures between -20° and $+25^{\circ}\text{C}$. Four sensors did not perform satisfactorily in these tests. The remaining sensors will be included in a long-term outdoor test.

1. Introduction

In meteorology, a reliable measurement of humidity at automatic stations where regular maintenance is not possible is still a problem. During the symposium on moisture and humidity, held in Washington DC in April 1985, it was shown that since 1963 the sensors for industrial applications have been improved considerably (ISA, 1985). However, for measurements in meteorological conditions characterized by frequent high humidities and condensation (especially in sea climates and the tropics) still no suitable sensors are available that can be used at automatic stations.

A laboratory test was performed under simulated meteorological conditions with the most promising commercially available sensors. Final approval of a sensor for meteorological use cannot be obtained by laboratory experiments only, but further requires a long-term outdoor test. Sensors which have shown a good performance in the laboratory will be included in a future field test. In this paper we report the results of the laboratory comparisons.

2. Prospects of various types of sensors

Based on the available literature on the performance of humidity sensors (e.g., McKay, 1978; Schurer, 1981; Visscher and Schurer, 1985; Muller, 1985) and on our own experiences at KNMI, we expect the following improvements in the performance of humidity sensors. Special emphasis was given to the performance at high humidities and the long-term stability without frequent maintenance (at best every half-year). For meteorological measurements an accuracy of about $\pm 5\%$ RH below 50% RH and $\pm 2\%$ RH above 50% RH is required (WMO, 1983).

(a) Psychrometer: Sound principle, but requires regular maintenance and cannot be used below 0°C . No improvements expected.

(b) Mechanical (e.g., hair): Principle fundamentally inaccurate, regular maintenance required. No improvement expected.

(c) Polymer, capacity: Probably fundamental problems with long-term stability and at high humidities ("hysteresis"). If the saturation problem can be solved this is a very cheap type of sensor that might be renewed every half-year, making long-term stability less important.

(d) Polymer, conduction: See c.

(e) Electrolyte temperature (e.g., LiCl): No improvements expected. Regular maintenance required, accuracy insufficient.

The following five types of sensors are relatively new.

(f) Electrolyte, impedance: Long-term stability may be sufficient. This sensor is more expensive than sensors of type c, so that a good long-term stability is an important requirement.

(g) Dewpoint, optical dew detection: Sound principle. Traditional instrument requires too much maintenance, but the design can be improved.

(h) Dewpoint, capacitive dew detection: Sound principle, no test available. Probably requires less maintenance than traditional optical dewpoint sensor.

(i) Sulphuric acid, temperature difference: New principle, no test available.

(j) Infrared absorption: Sound principle, possibly problems during fog and at high humidities. Not commercially available.

A general problem with the "chemical" sensors (b, c, d and f), whose performance strongly depends on the chosen material, is the lack of fundamental research on the properties of the materials and on the mechanism of the water ab(d)sorption. Because the processes are not well understood, small changes in the manufacturing process unexpectedly can have large influences on performance. Thorough studies (e.g., as

started by Denton et al., 1985) might show the way to better and more reproducible sensors.

3. Selected sensors

Based on our expectations as described in the preceding section we selected the most promising commercially available sensors. Details on instrument types and manufacturers can be found in the Appendix. The following sensors have been included in the test:

A. Electrolyte impedance sensors

A1) Rotronic hygrolit: Several years of experience at sea platforms have shown us that this is a reliable sensor (Muller, 1985). However, the behavior at low temperature had not yet been analyzed. Three sensors have been used in the test.

A2) Novasina: This sensor is based on nearly the same principle as the Rotronic hygrolit, but in addition it has a fundamental physical temperature compensation. Two sensors with only one amplifier were available for the test.

B. Capacitive polymer sensors

Testing these sensors for meteorological purposes seems a waste of time, because of the apparently inherent problem of hysteresis effects after saturation. However, favorable personal communication led us to make two exceptions.

B1) Vaisala: Three sensors were purchased and two sensors borrowed from the manufacturer for the test.

B2) Rotronic hygrometer: Promising and remarkable is the fact that this sensor may be held under water without damage. Four sensors were purchased for the test.

C. Psychrometer, Jenway

This is an automatic handheld psychrometer sensor. Although this instrument is not suited for use at automatic stations, it was included in the test because such an instrument is often used to perform field checks of operational instruments. A systematic test had not yet been performed.

D. Dewpoint sensors

Two dewpoint sensors with different designs to minimize the contamination problem were included. Of each type, only one example could be purchased for the test.

D1) Endress+Hauser. Instead of an optical detection of the dew formation this sensor uses a capacitor to detect the dew. This sensor might be less sensitive to dirt because of the large difference in dielectric constant between water and dirt.

D2) Protimeter. Like most dewpoint sensors this sensor detects dew optically. While in other instruments the mirror is usually kept at dewpoint temperature us-

ing a feedback mechanism, this sensor uses a long cycle of cooling and heating and detects the moment of dew formation. This has a twofold advantage:

(a) The mirror is seldom wet and therefore probably attracts less dirt.

(b) Even if a dirt layer forms, the transition at dew formation will still be detectable. With a traditional mirror dewpoint sensor a dirt layer may easily be misinterpreted as dew.

A consequence of this long cycle is a slow measurement rate (up to about 10 minutes). For synoptic meteorological purposes this is not a severe disadvantage.

E. Sulphuric acid hygrometer

This sensor is based on the temperature rise of a concentrated acid solution when water is absorbed. The sensor is manufactured by Kamstrup Metro. For this test we could borrow one instrument from the manufacturer.

4. Test procedure

The sensors were subsequently subjected to a number of increasingly time-consuming calibrations. (Note: In this paper calibration means checking of the calibration of the instruments; no adjustments were made.):

1) Calibration at room temperature after storage for at least 16 h at a humidity below 50% RH.

2) Calibration at room temperature after storage for at least 72 h at saturation (100% RH).

The soak time at each of the six to ten humidity points was 30 to 60 minutes. After dry storage the calibration procedure was started at low humidities. After saturation the first point was about 95% RH.

3) Calibrations at +8° and -20°C.

At these temperatures the soak time at each of the four to six humidity points was 1 to 12 h. After the calibration at lowered temperatures an additional calibration at room temperature was performed. Sensors which performed unsatisfactorily at one of the steps were removed from the test procedure. In some cases a special experiment was performed to analyze the faulty performance.

In principle only the sensor was exposed to the low temperatures and high humidities while the amplifier and/or display unit was at room conditions. If the sensor was directly connected to a (pre)amplifier this was not possible. For the various sensors the following parts were exposed:

Novasina and Vaisala: sensor only.

Rotronic hygrolit: sensor + preamplifier.

Rotronic hygrometer: sensor + amplifier (complete instrument).

Kamstrup Metro: This instrument was completely placed in the humidity chamber because, otherwise,

water might condensate in the inlet tube (temperature in the chamber was above room temperature). For tests in the refrigerators only the inlet tube was led into the refrigerator.

Endress+Hauser and Protimeter: sensor + preamplifier.

Jenway: humidity chamber, sensor + preamplifier; refrigerator, complete instrument.

5. Test equipment

a. Room temperature

Humidities from about 20% to 99% RH at about $25^{\circ} \pm 5^{\circ}\text{C}$ were generated using a two-stream humidity chamber (KNMI design). The recirculating air can be led through a dry and/or a wet channel. The dry channel is filled with silica gel, and the wet channel is filled with coal which can be saturated with heated water at different temperatures. In this chamber the temperature cannot be regulated. When high humidities are generated a rise in temperature is unavoidable. In this humidity chamber a ventilated psychrometer was used as the primary reference. A Rotronic hygrolit sensor, which was not used for the comparison, was used to check for gross errors in the psychrometer reading. Homogeneity in the chamber was found to be better than 1% RH. The major test runs at room temperature were performed in the humidity chamber. Additional calibrations of the small sensors (Novasina, Rotronic hygrometer and hygrolit, and Vaisala) could be performed using titrated diluted LiCl solutions as manufactured by Rotronic (yielding 20, 35, 50, 65, 80, 95% RH). The use of saturated salt solutions was cumbersome and avoided. During four years we have calibrated many different sensors using both the LiCl solutions and the humidity chamber with a psychrometer and occasionally also an EG&G mirror dewpoint sensor as a reference. The agreement between the two methods was always within 1% RH. The reproducibility of the calibrations was $\pm 1\%$ RH using the LiCl solutions and $\pm 2\%$ RH in the humidity chamber.

b. Below room temperature

Temperatures of $+8^{\circ}$ and -20° were produced using ordinary refrigerators. Temperature and humidity were stabilized by mounting the sensors in an aluminum box with built-in ventilation. Small sensors were calibrated inside the aluminum box using the titrated LiCl solutions. For large sensors, silica gel, wet towels or large amounts of diluted LiCl solutions were used to produce different humidities. At these temperatures we did not dispose of a reliable reference instrument. Instead we used the Rotronic LiCl solutions as a reference, correcting with the small temperature correction supplied by the manufacturer. Looking at the results below room temperature, the lack of an independent reference should be kept in mind. Because the perfor-

mance of the Novasina sensor was closest to the LiCl solutions, this sensor was accepted as a secondary reference for calibration of the large sensors. Frequently its calibration was checked against the LiCl solutions.

At $+8^{\circ}\text{C}$ the calibration reproducibility is $\pm 2\%$ RH using the LiCl solutions and $\pm 3\%$ RH using the calibrated Novasina sensor. At -20°C the estimated accuracy is $\pm 4\%$ RH. It cannot completely be excluded that the LiCl solution starts to crystallize already at this temperature. In that case the errors, especially at high humidities, would be much larger. The test results obtained under those conditions must therefore be considered with care.

6. Results and discussion

The results are presented in Figs. 1a–h. Figures 1a–1g show the difference between the instrument reading and the actual relative humidity as a function of relative humidity. Sometimes more than one sensor of the same type was tested; they always showed approximately the same behavior. The figure shows the typical averaged behavior. For all sensors shown in Figs. 1a–1g the errors were mainly a function of relative humidity, and, to a lesser extent, of temperature. For the Kamstrup Metro sensor this is not the case. For this sensor the errors mainly depend on the mixing ratio. Therefore the deviation in mixing ratio as a function of mixing ratio is shown in Fig. 1h. We will now discuss the results for all sensors separately.

A. Electrolyte impedance sensors

A1) Rotronic Hygrolit (Fig. 1a)

At room temperature these sensors behave excellently. Small absolute deviations, very good repeatability (better than 1% RH), no hysteresis. At lower temperature the signal is repeatable, but a considerable correction is necessary, especially at -20°C .

A2) Novasina (Fig. 1b)

At all temperatures the absolute deviations are not larger than $\pm 5\%$ RH. At low temperatures the repeatability is about $\pm 2\%$ RH, at room temperature about $\pm 3\%$ RH. Unfortunately only a sensor more than one year old could be tested thoroughly. Results are very promising.

B. Capacitive polymer sensors

B1) Vaisala (Fig. 1c)

These sensors show the typical undesired “hysteresis” effect of capacitive polymer sensors. Complete recovery after saturation for about one day takes about one week. Because of these poor results, no low temperature experiments were performed.

The good experiences obtained elsewhere, which led us to include this sensor, were obtained with a heated sensor, a type which Vaisala no longer delivered. Very recently we obtained one handheld heated sensor from

FIG. 1. Deviation (equal to instrument reading minus actual humidity) against actual humidity for the following instruments: (a) Rotronic hygrolyt; (b) Novasina; (c) Vaisala; (d) Rotronic hygrometer; (e) Jenway; (f) Endress+Hauser; (g) Protimeter; (h) Kamstrup Metro.

Vaisala. Hysteresis effects turned out to be much smaller, but not negligible: 4% RH shift after 48 h at saturation.

B2) Rotronic hygrometer (Fig. 1d)

Apart from a large deviation at high humidities at very low temperatures, these sensors show otherwise very small deviations. Typical repeatability is about $\pm 2\%$ RH. No hysteresis effects were observed for this capacitive sensor.

C. Psychrometer: Jenway (Fig. 1e)

The performance of this small handheld psychrometer at room temperature is very good. However, if

used outdoors in winter the performance will be rather poor, even when the whole instrument is in thermal equilibrium with its environment.

D. Dewpoint sensors

D1) Endress+Hauser, capacitive dew detection (Fig. 1f)

The initial calibration of this sensor showed a rather large systematic deviation at low temperatures. After saturation the deviation also became large at low temperatures, with a very slow recovery (weeks to months). This result was unexpected for this type of sensor and might be due to a sensor defect (e.g., entrance of water

into the capacitive detection loop). The instrument will be inspected by the manufacturer.

D2) Protimeter (Fig. 1g)

Calibration at room temperature was perfect. The performance at 8°C showed a surprising systematic error with the largest deviation at high humidities. Shortly after this test—after a first try in the freezer—all results became erratic, probably due to condensation after removal from the freezer. However it is not completely sure that the sensor was still in good working order during the 8°C test. Very slowly the sensor recovered from its erratic behavior. The sensor was sent back to the manufacturer for inspection.

E. Sulphuric acid sensor, Kamstrup Metro (Fig. 1h)

Very large deviations were observed, especially at high absolute humidities and after saturation. These deviations were not caused by condensation in the inlet tube, as the whole instrument was placed in the humidity chamber. Although the manufacturer had discovered that a small correction is necessary at high humidities (see Fig. 1h), this correction cannot explain the observed deviations. A possible explanation is a leaking connection of the acid bottle so that the acid becomes diluted. If that is the case it is very unpleasant that the user has no possibility to check the quality of the acid.

7. Conclusions

The following sensors showed a performance which justifies their inclusion in a long-term field test:

Rotronic hygrometer	
Nova Sina	(more extensive test of repeatability required)
Rotronic hygrolit	(application of a correction at low temperatures necessary)
Protimeter	(investigation of the problems after freezing required).

These sensors will not only be tested at KNMI, but will also be included in the WMO International Hygrometer Intercomparison, which will be held in Norway from 1986 to 1988.

Based on their performance at room temperature the remaining sensors cannot be recommended for automatic meteorological measurements in their present form. The Jenway psychrometer can be used for field checks if the temperature is between about 15° and 30°C.

APPENDIX

Instrument Types and Manufacturers

Instrument: Hygrolog WMT 170
Manufacturer: Endress+Hauser GmbH+Co

Hauptstrasse 1, D-7867 Maulburg
tel: (07622) 28-0, telex 773226

Instrument: Jenway 5500
Manufacturer: Jenway Ltd
Gransmore Green, Felsted, Dunmow, Essex CM6 3LB (UK)
tel: (0371) 820122, telex: 817766

Instrument: Kamstrup 0A11
Manufacturer: Kampstrup-Metro A/S
Jacob Knudsensvej 12, DK-8230 Aabyhøj (Denmark)
tel: +456257611, telex: 64100

Instrument: Novasina TR23/e83E-4
Manufacturer: NOVASINA AG
Thurgauerstrasse 50, 8050 Zürich (Switzerland)
tel: (01) 3014000, telex: 56956 sinach

Instrument: Protimeter Dewpointmeter DP 383R
Manufacturer: Protimeter
MeterHouse, Fieldhouse Lane, Marlow, Bucks, SL7 1LX (UK)
tel: (06284) 72722, telex: 849305 pmetr g

Instruments: Rotronic Hygrolyt H.T.S./DMS100H(PGHST) and Hygrolyt HTW
Manufacturer: Rotronic AG
Badenerstrasse 435, CH-8040 Zürich (Switzerland)
tel: (01) 4923211, telex: 822530

Instrument: Vaisala HMP 123Y
Manufacturer: VAISALA OY
P1 26, SF-00421 Helsinki 42 (Finland)
tel: (+3580) 89491, telex: 122832 vsala sf

REFERENCES

- Denton, D. D., J. B. Camou and S. D. Senturide, 1985: Effects of moisture uptake on the dielectric permittivity of polyimide films. *Instrum. Soc. Amer.*, 505-514.
- Instrument Society of America, 1985: *Proc. Int. Symp. on Moisture and Humidity*, Washington DC.
- McKay, D. J., 1978: A sad look at commercial humidity sensors for meteorological applications. *Proc. Fourth Symp. on Meteorological Observations and Instrumentation*, Denver, 7-14.
- Muller, S. H., 1985: Operational experience at sea locations with a humidity sensor based on the impedance measurement of an electrolyte. *Instrum. Soc. Amer.*, 643-648.
- Schurer, K., 1981: Humidity sensors. *Journal A; Quart. J. Automatic Control*, Brussels, 22, 156-161.
- Visscher, G. J. W., and K. Schurer, 1985: Some research on the stability of several capacitive thin film (polymer) humidity sensors in practice. *Instrum. Soc. Amer.*, 515-524.
- WMO, 1983: Guide to Meteorological Instruments and Methods of Observation. Commission for Instruments and Observing Methods, WMO Publ. No. 8.