Preliminary Tests of an Expendable Balloon-Borne Dew Point Hygrometer

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ABSTRACT

Efforts are described involving the development of an expendable, balloon-borne dew point hygrometer which is compatible with standard radiosonde equipment, maintains the inherent accuracy of this sensing technique, and as far as is possible reduces the cost. Presented here are both laboratory and field test data on a selected number of flights, together with a description of the device and its operation.

1. Introduction

Water vapor is one of the most important atmospheric constituents and its accurate determination is of prime concern to the meteorologist and climatologist, together with a broad spectrum of specialists in other fields. Its effects on weather processes and atmospheric properties are inordinately greater than its relative concentration would indicate.

The wide range of water vapor concentration ($>10^4$ dynamic range) encountered in the troposphere presents a formidable problem to the sensor specialist. The vast majority of humidity data collected in this country is obtained by weather balloons equipped with a carbon humidity element. The accuracy of this relative humidity element is approximately $\pm 5\%$ for temperatures above 0C and relative humidities between 25 and 85%. For temperatures below 0C down to -40C, the accuracy is approximately $\pm 10\%$. Quoted accuracies are for steady state conditions and do not reflect uncertainties due to dynamic sensing problems encountered in flight.

While these accuracies are useful for routine weather forecasting, they do not meet stated requirements nor are they suitable for atmospheric research programs, for electromagnetic propagation corrections, nor for inputs required for the computerized atmospheric models presently being developed for prediction. A clear cut need exists, therefore, for a more accurate hygrometer for nonroutine applications.

Because of the basic well-understood principles involved in dew point hygrometry, and the large amount of work performed by other researchers using this technique, a program was initiated at AFCRL to develop a suitable expendable optical model.[1] To date, the high cost of balloon-borne dew point hygrometers has limited the total number of soundings to only a few dozen, and these have usually been concerned with stratospheric data.

2. Design considerations

For maximum utilization, the instrument should be completely compatible with the existing radiosonde equipment and therefore have a gross weight not in excess of about 2000 gm. Though efforts have been made to extend the lower range of frost points measured, immediate attention has been directed to frost-point temperatures down to -60C. Peltier devices do not have the depressional capability to cover the desired range of meteorological interest; thus, the use of a chemical heat sink was investigated.

Refrigerants of the Freon type were selected as coolants due to their inertness, ready availability and low cost. Freon-22 ($CHClF_2$) was used in the early instruments. Currently, Freon 502, an azeotropic mixture of $CHClF_2$ and $CClF_2CF_3$ is employed. The boiling points of these fluids at atmospheric pressure are -40.8 and -45.6C, respectively. Lower boiling fluids are available but require high pressure bottles and would thus reduce the amount of fluid capable of being carried aloft. A 1-lb can of refrigerant will last for over one hour and is sufficient for a normal radiosonde flight. For longer flights, the package could be modified to accept more fluid.

The air sample is ducted by forced ventilation through a small stainless steel tube extending 4 inches from the side of the package. A motor driven fan provides aspiration across the mirror at about 200 ft min^{-1}. These units currently use a 4.5 V silver-zinc battery for sensor power and for a heater to keep the Freon can sufficiently warm to maintain adequate delivery pressure. Overall package dimensions are 16 inches long by 5 inches wide by 5 inches deep (see Fig. 1).

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[1] The hygrometer development was conducted in conjunction with Cambridge Systems, Inc., Newton, Mass., under Contract AF19(628)-5079.

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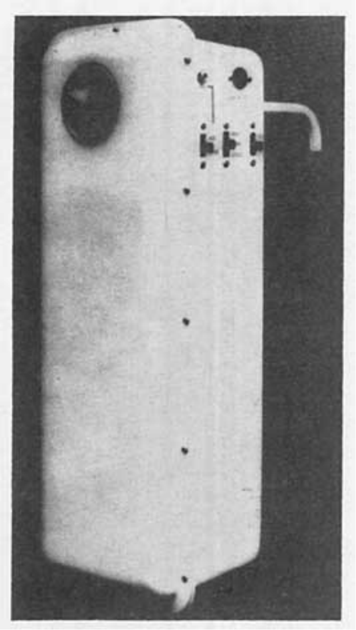

FIG. 1. Photograph of the dew point hygrometer.

3. Sensor head and electronics

A cross-sectional view of the sensor head assembly is shown in Fig. 2. The chemical coolant is fed by its own vapor pressure through a narrow rate-limiting capillary into a copper reservoir which serves as the mirror heat sink. This cooling procedure was found to be more satisfactory than direct impingement of coolant on the base of the mirror thimble as a more uniform temperature is maintained which is less subject to spurting and splashing caused by pressure surges of the Freon issuing from the capillary.

Fig. 3 is a block diagram of the hygrometer head and electronics. The mirror surface is monitored with a beam of light and matched photo-resistors in a bridge arrangement. The photo-resistors sense bias and reflected light. As moisture condenses on the cool mirror surface, the ratio of bias to reflected light changes abruptly causing a change in bridge output. This output is used to proportionally increase the current introduced into a resistance heater surrounding the sensor thimble. By maintaining a constant condensate layer thickness, the dew point temperature of the air stream is thereby tracked. A small bead thermistor is used to monitor the mirror temperature. This resistance is fed into the blocking oscillator circuit of the radiosonde to which it is interfaced and is then telemetered to a ground receiver along with the other usual meteorological data.

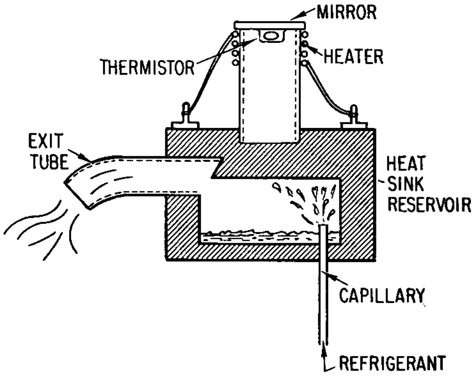

FIG. 2. Diagram of hygrometer mirror assembly.

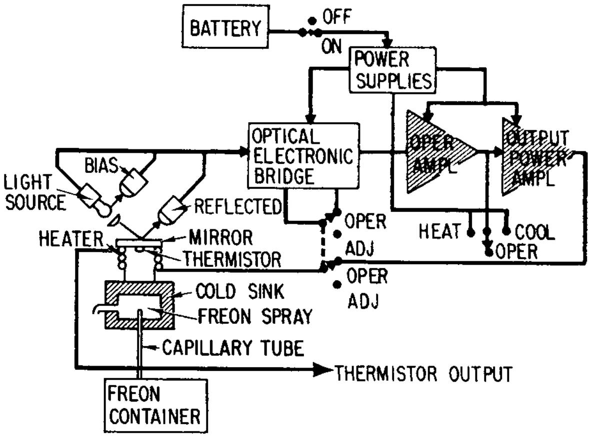

FIG. 3. Dew point hygrometer block diagram.

4. Operational characteristics

To assess the temperature depressional capability of the hygrometer, the temperature of the heat sink and the mirror surface were monitored under conditions of full cooling in an environmental test chamber. The data are displayed in Fig. 4, along with the theoretical boiling point pressure relationship for Freon 502.

It may be noticed, above 400 mb, that the effects of ambient air temperature are minimized and the mirror

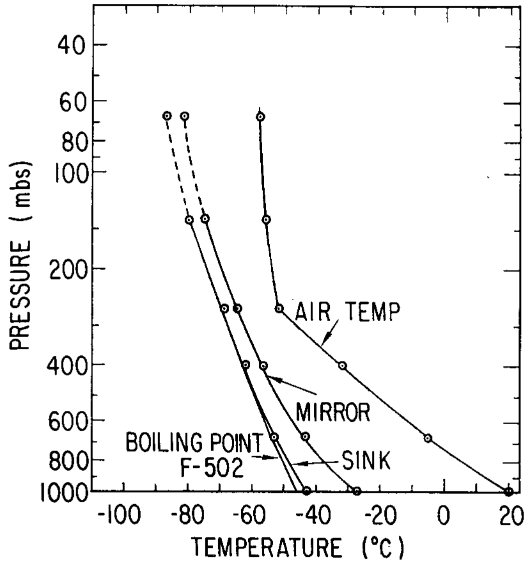

FIG. 4. Mirror temperature depressional capability with Freon-502.

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surface approaches a constant value of approximately 5C above the heat sink temperature. At lower altitudes, the depressional capability of the hygrometer should encompass all dew or frost point temperatures normally encountered meteorologically.

To derive a maximum of information in this development program, the hygrometer is interfaced with a modified AMT-12 radiosonde. The sonde incorporates a clock commutator to sample the dew point and heat sink temperatures, in addition to pressure, ambient temperature and relative humidity.

The power from the radiosonde, fed into the small bead thermistor used for dew point readout, introduces a Joule heating temperature bias of up to 0.7C. This error, however, is readily corrected and ultimately can be accounted for in a computer wheel for data processing.

In a laboratory study, the accuracy of the hygrometer was compared with a precision dew point hygrometer having an NBS calibration traceability. Over the dew or frost point range of +7 to −30C, the instrument tracked the dew point to within 0.3C.

The mirror assembly was found to conform closely to Newton's law of cooling, i.e. $dT/dt=-k(T-T_0)$. At 1 atm and ambient air temperature, the velocity coefficient of cooling, k, was found to be 0.157 sec^{-1}. Thus, for these conditions, the minimum time to respond to a 50% relative humidity change (88% to 38%) from a dew point of +20C is 2.0 sec. For more drastic conditions, involving a change from a 10C dew point to a −10C frost point (a relative humidity change from 46.5% to 10%), the time would be 5 sec.

The velocity coefficient at 400 mb and an ambient air temperature of −32C is approximately 0.13 sec^{-1}. Under these conditions, a change in relative humidity from 100% to 50% requires a minimum of 2.1 sec against a heat sink of −57C.

At very low frost points it should be noted that the low mass transfer rates for water vapor will also become an important factor in response by determinations.

It is interesting to compare these values to those of the ML-476 carbon element. Table 1 gives the average lag times for the carbon element (extracted from the data of Grote and Marchgraber, 1963) to attain 50% and 90% responses to an input humidity change.

If we accept a 90% response as being a realistic criterion for the evalutaion of meteorological data using the carbon element, we see that the laboratory lag times of the optical hygrometer compare favorably at high dew points and are considerably superior at low frost points. This was also borne out by an examination of the field test data.

TABLE 1. Carbon element ML-476 response lags (sec).

	50% response	90% response	Ambient temperature (°C)
Increasing RH	0.3	1.0	+25
Decreasing RH	0.2	2.9	
Increasing RH	0.9	20	−5
Decreasing RH	1.6	48	
Increasing RH	2.1	78	−20
Decreasing RH	4.6	120	

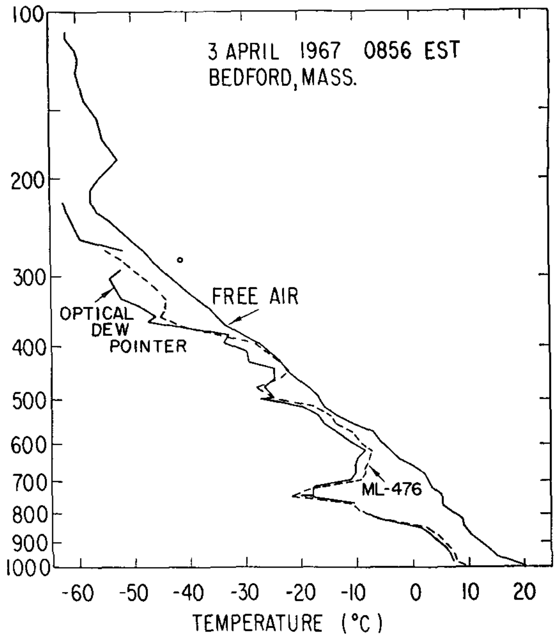

FIG. 5. Dew point hygrometer flight test, 3 April 1967.

5. Field test data

The dew point hygrometers (also referred to as dew pointers) were flown using 1200-gm ML-537 weather balloons, the train consisting of a balloon, parachute, hygrometer package and radiosonde. The separation between the balloon and the hygrometer package is ~50 ft. In addition to the hygrometer package information, the radiosonde telemetered the usual meteorological data of temperature, pressure, and humidity.

The data from four flight tests are shown in Figs. 5–8. Carbon element humidity data for these flights have been converted to frost-point values for those vapor pressures below the 0C saturation value so that a direct comparison can be made with the optical dew pointer.

As the data presented have been smoothed, some of the humidity fine structure at the lower temperatures which was observed with the optional hygrometer but not seen with the carbon strip have been lost.

Fig. 5 shows the data from 3 April 1967. There were scattered cloud observations at 2200–2500 ft and at 12,000–13,000 ft, corresponding to pressure levels of 930 and 630 mb. Neither sensor indicated saturated conditions at these levels, although a humidity peak in both sets of data is noticeable at about 618 mb. The agreement between the two sources of humidity data is seen to be excellent to 700 mb (~0C ambient), although the

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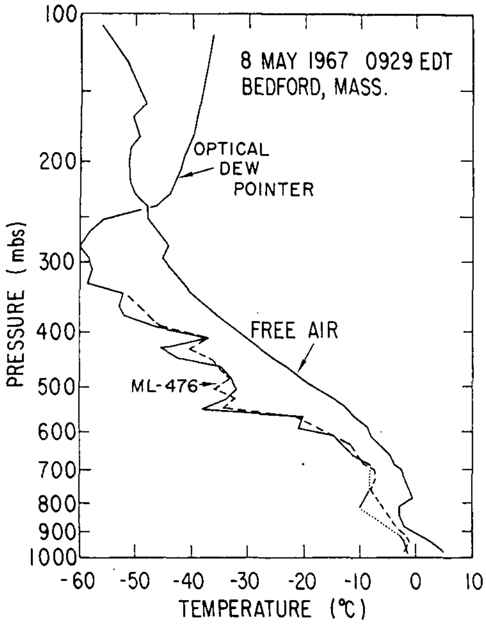

FIG. 6. Dew point hygrometer flight test, 8 May 1967.

profiles diverge somewhat up to 500 mb (∼−20C ambient). Above this level the differences are considerably larger, amounting to ∼8C in dew point at 330 mb (−40C ambient). The dew pointer went out of control at about 280 mb as indicated by the supersaturation (circled point), and it is felt that the dew point data between 260 and 300 mb are suspect. The saturated condition indicated by the carbon element was not correlated to any cloud observations, but it should be noted that this saturation is with respect to ice.

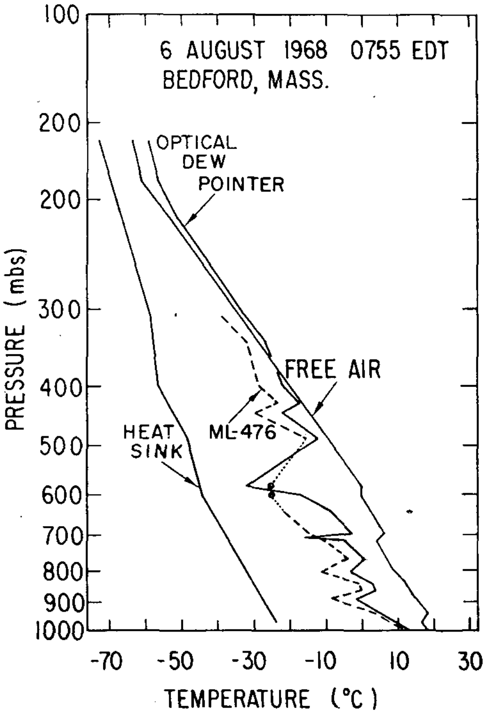

FIG. 7. Dew point hygrometer flight test, 6 August 1968.

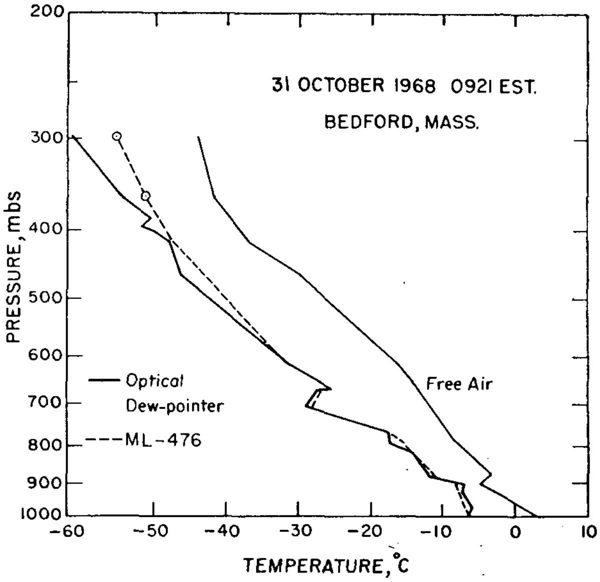

FIG. 8. Dew point hygrometer flight test, 31 October 1968.

Fig. 6 gives the results for 8 May 1967 in which much of the optical hygrometer data were lost in the early part of the flight due to electrical problems. There was broken cumulus at 2500 ft (910 mb) and overcast at 4000 ft (875 mb). The agreement between the two profiles is excellent to ∼550 mb (−10C ambient), except for one point at 810 mb which is in the area where most of the dew point data are missing, and is consequently suspect. Above 550 mb, the agreement often deteriorates with 4–5C differences. Due to the dry state of the atmosphere on this day, this discrepancy amounts to a relative humidity difference of only 8–10%. The dew point hygrometer lost its cooling capability at about 33,000 ft (275 mb).

Fig. 7 shows the data from a flight on 6 August 1968. The heat sink temperature was monitored on this flight and is shown in the figure with the humidity data. The agreement between the two sensors is noticeably poorer than in the other flights. This disagreement begins at about 3500 ft (900 mb) and ranges from 4–16C. Above 27,000 ft (350 mb), the dew pointer indicates supersaturation with respect to ice. However, when these data are presented as dew point, with respect to water, only the point at 340 mb and the upper limb of the curve indicate saturation. This was in excellent agreement with cloud observations of scattered clouds from 27,000–29,000 ft. If there were clouds at the upper level, it might be thin cirrus which often are not noticeable from the ground. It is noteworthy that between 27,000 and 29,000 ft, the dew point difference between the dew pointer and the carbon element is equivalent to a relative humidity difference of 50%.

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Fig. 8 shows the data from a flight on 31 October 1968. This was the only flight of those presented where Freon-502, which has a greater depressional capability, was used. The agreement between the two profiles is exceptional, being within about 1C dew point and 2–3% relative humidity up to 16,000 ft (550mb). The sharp inversion and the corresponding humidity maximum at 3100 ft (905 mb) agrees with an estimated height of about 3000 ft of scattered clouds in the distance. There were no clouds overhead. The agreement above 550 mb is still very good with a maximum discrepancy of only 3.5C and 8% relative humidity up to where the atmospheric temperature is −40C. Above this level (~400 mb), the carbon data are not considered valid.

6. Conclusions

The dew point hygrometer described here is at a stage that will provide useful data on atmospheric humidity up to about 200 mb when used on meteorological balloons. The accuracy of this device is better than 0.5C above 0C dew points; better than 1.5C above −40C dew points; and better than 3C above −60C. These figures do not include balloon contamination effects which are thought to be appreciable below dew points of −60C. The field test program to data has shown that at temperatures above 0C, the carbon element and dew point hygrometer generally agree to within 5–7%, whereas this deteriorates to 10–12% below 0C, becoming much larger below about −25C. As might be expected by the faster response time, the dew point hygrometer data show more detail above about 700 mb, reflecting its faster response at lower temperatures.

REFERENCES

Marchgraber, R. M., and H. H. Grote, 1965: The dynamic behavior of the carbon humidity element ML-476. *Humidity and Moisture*, Vol. I. New York, Reinhold Publishing Corp., 331–345.

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