Dew-Point Hygrometer with Constant Resistance Humidity Transducer¹

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(Manuscript received 7 March 1969, in revised form 23 September 1970)

ABSTRACT

A dew-point hygrometer with a constant resistance humidity transducer is described which uses the salt solution phase transition of lithium chloride as its basis of operation. The hygrometer employs electronic error detection and signal amplification to control the heat applied to the humidity transducer and to keep its resistance at the preselected value. Using this method a high accuracy of measurement can be achieved. Sufficient transducer area is exposed to the ambient environment to assure operation at the lithium chloride salt solution phase transition. This also minimizes error from contamination. The feature characteristics of this unit are: 1) low power requirements, 2) operation of the humidity transducer at a nearly constant preselected LiCl film resistance, 3) small transducer size suitable for micro-climate study, 4) balanced operation between transducer and electronics, and 5) interchangeability of humidity transducer units.

1. Introduction

Study of watershed performance in the mountainous areas of Utah has presented exacting need for accurate measurement of air moisture. The dew point is an important property in these moisture studies. Since only a few of the measurement locations are equipped with commercial electrical power, most locations require battery power for operating the instrumentation.

To measure dew point at remote sites, equipment is needed which is battery powered with low power drain, accurate, and requires little maintenance. Experience with a variety of atmospheric humidity sensors led to a preference for those using the salt solution phase transition principle. This type instrument is rugged and measures a wide range of humidity. The result is given in temperature which can be easily converted to a humidity value. Since commercial units were not adaptable to our needs for remote locations the constant resistance lithium chloride film hygrometer (CR hygrometer) described below was developed.

2. Performance considerations

To meet our needs for a remote location instrument, the hygrometer had to operate over 1) a dew-point range of -10 to 25°C , 2) use a 12 V battery, 3) consume less than 0.75 W and 4) have an accuracy of $\pm 0.5^{\circ}\text{C}$.

3. Lithium chloride as a hygroscopic agent

Nelson and Amdur (1965) presented an excellent discussion of salt solution phase transition hygrometry,

while Acheson (1965) pointed out the importance of knowing the vapor pressure of inorganic salt solutions in hygrometry. Lithium chloride is one of the most active hygroscopic salts and from the writing of the above authors, further examination of LiCl was found to be warranted.

Dissolving LiCl salt in water lowers the vapor pressure of the water over the solution. This occurs due to the increased attraction between molecules in the solution. Increasing the amount of LiCl added to the water will continue to decrease the vapor pressure until the amount of salt added exceeds the amount that will dissolve. When water contains all of the salt that it can dissolve, it is called a saturated solution. By adding more salt than will dissolve to assure continuation of the saturated condition, we obtain the minimum electrical resistance condition (MERC).

Fig. 1 shows the vapor pressure vs temperature curves over a pure water surface (curve A) and over a saturated lithium chloride solution (curve B). The conditions at points A, D and F are selected to illustrate the vapor pressure and temperature relationships.

If the vapor pressure of the space is decreased to point D, the water will evaporate and dry salt will remain. When the vapor pressure is changed to D, the MERC may be re-established by cooling to E.

If the vapor pressure is increased from points A to F by adding water vapor, moisture will be absorbed into the solution, the solid salt will dissolve, and a solution will remain. When the vapor pressure is changed to F, the MERC may be re-established by heating to G.

The temperature at which the MERC is established indicates the vapor pressure at the new vapor phase condition. This temperature may be readily converted

¹ Approved by the Director, Utah Agricultural Experiment Station, as Journal Paper No. 879.

FIG. 1. Vapor pressure vs temperature curves over a pure water surface (curve A) and a saturated lithium chloride solution (curve B). See text for further explanation.

to the conventional dew-point temperature as illustrated in Fig. 1 by proceeding on a constant vapor pressure from A to B until intersecting the curve for pure water and then proceeding down to C on the temperature axis. The point of intersection on the temperature axis is the dew-point temperature.

Fig. 2 shows the resistance of a LiCl solution as it is elevated to higher temperatures and held there until equilibrium is achieved. The equilibrium is achieved by driving off some of the water which, in turn, increases the salt concentration. The data for Fig. 2 were obtained in a closed chamber over a water surface at 25C.

In most dewcell hygrometers the resistance of the LiCl solution is utilized to heat the unit until it reaches equilibrium. This equilibrium condition is a function of ambient temperature and dew point. Thus, the resistance point at which equilibrium will be reached, according to Hedlin and Trofimenkoff (1965), will usually be somewhere between 500 and 5000 Ω . By referring to Fig. 2 we see that this represents a spread in temperature of $\sim 3^\circ\text{C}$ due to heat load requirements.

4. Functional characteristics

Physical units which are necessary to give the desired performance stated in Section 2 are 1) a heater, 2) a dc to ac converter, 3) a humidity transducer, 4) a resistance error detector and control, and 5) a temperature-sensing device and readout equipment. The relationship among these units is displayed in Fig. 3.

5. Hygrometer design

A schematic and a parts list for the hygrometer are shown in Fig. 4. The function served by each part is

given in the following discussion. The use of trade names is not intended as an endorsement or recommendation; equivalent parts from another manufacturer would be equally suitable. All voltages are referenced to the negative supply.

FIG. 2. Electrical resistance of lithium chloride film as a function of temperature.

Fig. 3 includes two items not included in Fig. 4, i.e., a 12 V battery and a temperature readout device. Since these are usual laboratory items and not unique to this use, they are omitted.

Parts 1, 2 and 3 are resistors for establishing the dc operating conditions for the oscillator transistor (part 7). Parts 4, 5 and 6 are the additional items required to complete the conventional resonant feedback oscillator circuit.

The ac output from the oscillator transformer secondary is applied across parts 9 and 12. Part 9, which is a part of part 8, consists of two electrodes wound over a LiCl solution absorption pad. This unit (part 9) connects into the circuit to sense the LiCl film resistance.

Parts 12, 13, 18, 19 and 20 establish the normal dc conditions for the transistor (part 17). Part 17 is normally non-conducting until a signal of sufficient amplitude and with proper polarity appears across part 12. The polarity of this signal must be positive with respect to the negative supply line for conduction to take place.

The humidity transducer consists of parts 9, 10, 11 and 8, which are packaged collectively as part 8. The resistance of the LiCl film is controlled by the hygroscopic characteristics of LiCl and the heat applied to it.

In operation, as the LiCl attracts moisture from the air its resistance is decreased and the voltage across it decreases causing the voltage across part 12 to increase. This increases the signal drive through the base series resistor (part 13) to part 17. Part 17 is the error signal

FIG. 3. Block diagram showing functional parts required in the hygrometer with arrows indicating the direction of power flow and control.

FIG. 4. Constant resistance hygrometer schematic with part identification numbers.

Parts list

1. 27,000 Ω resistor	11. YSI 44005 thermistor
2. 6800 Ω resistor	12. 10,000 Ω resistor
3. 470 Ω resistor	13. 2700 Ω resistor
4. 0.1 μ F condensor	14. Test point number 1
5. 0.1 μ F condensor	15. Test point number 2
6. TY 34 Triad transformer	16. Test point number 3
7. 2N 3704 transistor	17. 2N 3704 transistor
8. Keystone relay case with octal base	18. 1000 Ω potentiometer
9. Electrodes for sensing lithium chloride film resistance	19. 2000 Ω resistor
10. 51 Ω resistor for heating transducer	20. 4700 Ω resistor
	21. GE D27D1
	22. 4.7 Ω resistor
	23. Barrier terminal block

amplifier which causes current to increase through parts 18 and 19 to the base of the heat control amplifier (part 21.)

The increase in base current of the heat control amplifier causes an increased current flow through parts 22 and 10. Part 22 provides a series feedback for the heat control amplifier, making it less sensitive to variations in individual transistor characteristics. The increased current in part 10 produces heat which is directly applied to parts 11 and 9. This increases the temperature of the LiCl and causes its resistance to increase, thus closing the feedback loop and correcting the resistance error that started the cycle.

6. Adjustment

The voltage output of the transformer secondary is 4.8 V. Part 18 is adjusted until the voltage between test points 1 and 2 equals the voltage between test points 2 and 3 when steady-state operation is achieved. The laboratory prototype unit has been adjusted while operating in a closed chamber containing melting ice and then operated from -10 to 25°C . From the 2.4 V setting the voltage increased to 2.5 V at -10°C and decreased to 2.2 V at 25°C . This change in voltage is a function of the change in energy requirement necessary to establish an equilibrium condition.

7. Humidity transducer

Fig. 5 shows the assembled CR hygrometer on the left with the humidity transducer (part 8) plugged into

the oscillator and control unit. The right-hand view shows the separated parts, located with respect to their position in the hygrometer. The numbers by the parts refer to the parts list (Fig. 4).

The assembly of the transducer may be accomplished as follows:

- 1) Install the ohmite 51Ω resistor (part 10) in pins 3 and 6 of the octal plug of part 8 and solder leads.
- 2) Spread the leads of the YSI 44005 thermistor (part 11) 180° apart, then install the thermistor in the hollow core of the 51Ω resistor. The thermistor bead should be near the center of the resistor. The thermistor leads are then inserted into pins 2 and 7 and soldered; they should not be stressed at any time.
- 3) Place the fiber glass of part 9 on the 51Ω resistor and hold it in place with an alligator clip while connecting the electrodes.
- 4) Connect the end of one electrode of part 9 to pin 1 of the octal plug; wrap one complete turn around the resistor and connect the other end to pin 4. Connect the second electrode to pin 8 and wrap around the resistor in the opposite direction to the first, terminating in pin 5. Care must be taken to insure that the two electrodes are adequately spaced from each other. The only electrical connection that exists between them is through the salt film. Solder the electrodes in place.
- 5) Apply a good heat sink compound to the thermistor to insure thermal equilibrium with the resistor temperature.

Then seal the ends of the resistor core with a silicon rubber sealer.

This completes the assembly of the humidity transducer and it is now ready for servicing preparatory for use.

The salt density tolerance is quite broad for phase transition hygrometers, but errors of several degrees and/or stability have been observed with insufficient or excessive salt. This condition is controlled by developing and following uniform procedures for handling and servicing. The following procedure has proved to be close to optimum for this transducer.

A saturated solution of LiCl should be prepared in advance of the time it is to be used. For treating the transducer, mix 1 part by volume of saturated LiCl solution and 1 part distilled water. Using a dropper, apply enough to wet the fiberglass, then shake off any excess. Care should be taken to insure that the solution does not get on other parts of the transducer.

Ventilation of the transducer may be controlled by installing the ventilation shield of part 8. A hole is drilled through opposite sides of the shield as shown in Fig. 5. The amount of ventilation depends on the size and orientation of these holes. Usually the transducer is mounted so that the holes are in the vertical plane.

The transducer must be periodically cleaned and retreated with LiCl. Before adding new LiCl solution, perform the following check to see if the cleaning is

FIG. 5. Assembled (left) and separated components (right) of constant resistance dew-point hygrometers. See legend to Fig. 4 for identification of part numbers.

FIG. 6. Transducer temperature vs dew-point temperature (all units, °C).

adequate. After washing, plug the wet transducer into the oscillator and control unit and observe the results. If the unit is clean, it will heat up until dry, after which it will return to ambient temperature. If it does not return to ambient temperature, it is not clean.

8. Test method and calibration

Calibration data were obtained by using an ice and water system in a closed chamber where the temperature

FIG. 7. Warm-up response curve for constant resistance hygrometer with the humidity transducer in a 0°C dew-point environment.

FIG. 8. Transient response curves for constant resistance hygrometer with humidity transducer in a 0°C dew-point environment. See text for explanation.

rise throughout the range from -15 to 30°C was less than $1^{\circ}\text{C hr}^{-1}$. Under these conditions the air was regarded as having reached the saturation vapor pressure condition at the temperature read by the thermometer.

The closed chamber contained: 1) a quartz thermometer temperature-sensing element, 2) a humidity transducer, 3) a pump for circulating the water as it became available from ice melt, 4) an immersion-type electric heater, 5) an air circulating fan, and 6) truncated cones of ice made by freezing ice in 5 ounce paper cups.

The closed chamber was a freezer capable of producing temperatures as low as -40°C .

The fan was placed to draw air from the bottom of the ice pack past the thermometer sensor and the humidity transducer, then blow it back to the far end of the chamber. The thermometer was located so that it was in the air stream during the ice phase and immersed in

TABLE 1. Chamber and hygrometer transducer temperatures as a function of the calibration chamber temperature change (all units, °C). See text for description of sensors.

Chamber temperature	Sensor number					
	1st run		2nd run		Extra sensors	
	1	2	3	4	5	6
-10.00	20.8	21.0	21.2	21.1	21.0	21.1
-5.00	27.0	27.3	27.2	27.2	27.5	27.1
-1.00	32.7	32.8	32.6	32.7	32.9	32.8
0.00	37.8	37.8	37.6	37.6	38.2	37.5
5.00	43.3	43.5	43.0	43.2	43.8	43.2
10.00	49.1	49.2	49.1	49.1	49.6	49.2
15.00	55.9	56.0	55.8	55.9	56.0	55.8
20.00	62.8	62.9	63.0	63.0	63.1	63.1
25.00	69.5	69.4	69.3	69.6	69.7	69.3

the water as the ice melted. The humidity transducer was placed above the thermometer sensor so that it would be just above the water when the ice melted.

The heater and pump were placed in the chamber before operation so that it would not require opening at any time during the calibration period.

Testing was started by cooling the chamber to -30°C , then allowing it to gradually warm. The results are given in Table 1 and plotted in Fig. 6 as a curve of dew-point temperature vs transducer temperature. Table 1 gives the temperature read from the thermometer and the simultaneous temperatures of the humidity sensors. Sensors number 1 and 2 were processed through a calibration run, washed and retreated with LiCl solution, and then processed through another calibration run and recorded as numbers 3 and 4. It can be seen that there is no significant change in response due to the washing and retreating of the sensors.

9. Hygrometer response

Fig 7 is the warm-up response curve for the hygrometer with the humidity transducer in a 0°C dew-point environment. The equipment had been turned off for a period of 15 min before starting this response curve.

Fig. 8a was obtained by turning off the power to the hygrometer until the resistance of the LiCl film was reduced to one-half its operating value. At this point the power was turned on and the time was indicated as time zero. Stability was achieved within 4 min. The curve in Fig. 8b was obtained by turning off the hygrometer power at time zero and leaving it off for 15 sec. During this time the LiCl film resistance dropped to 80% of its operating value. The power was then turned on and stabilization was achieved within 4 min. Within this range of humidity transients, the response time is more dependent on the transducer characteristics than on the magnitude of the humidity transient.

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