THE RELATIVE ACCURACY OF CERTAIN METHODS FOR MEASURING RELATIVE HUMIDITY

by

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INTRODUCTION

The measurement of water vapor in the air was one of the first physical determinations made by the early investigators who developed methods of measurement, some of which have been accepted as standard. These methods, with certain modifications, are still used in the determination of humidity. The results secured by these different methods are not always in agreement, and it was to investigate some of these disagreements that this research was begun.

PURPOSE OF THESIS

The purpose of this research was to investigate the agreement between certain methods commonly used in the measurement of relative humidity.

HYGROMETRIC METHODS NOW IN USE

The name humidity is given to the invisible water vapor present in the air. It is measured by its pressure or by its mass per unit volume of air. The greatest mass of water vapor which a unit volume of air can hold at a given temperature is known as saturation for that temperature. The actual mass of water vapor in a unit volume of air is known as absolute humidity. The ratio of the pressure of water vapor to the saturation pressure at a given temperature is called relative humidity. The maximum vapor pressure, at a stated temperature, has been shown by Regnault (Relation des experiences Memores de l' Academie t xx) to depend only upon the temperature.

The methods for finding the humidity are arranged into five classes (1) depending upon finding the dew point; instruments having been developed by Alluard, Dines, Regnault, Daniel, Crova and others; (2) depending upon lowering the temperature of a wet bulb thermometer due to evaporation; a number of commercially made instruments being used; (3) in which the actual mass of water vapor in a given volume of air is measured; (4) depending on the change of pressure of the air when the water vapor is removed by absorption and (5) depending upon the use of hygroscopic substances such as hair, horn, etc.

This research is limited to the study of those instruments generally used in research and in laboratory experiments, and consists of the following classes and their instruments: Class one, an Alluard dew point; class two, a Sling psychrometer, a Lloyd's hygrodeik with a computer and a wet and dry bulb hygrometer referred to as the Tycos hygrometer, all made by the Tycos Company; and the Exhaust

Psychrometer; class three, the classical chemical apparatus; and class four a precision hygrometer and a recording hygrometer, or hygrograph, both containing hairs.

THEORY OF OPERATION

The dew point is that temperature at which the air would be saturated with the water vapor present in it. The pressure at the dew point can be secured from vapor tension tables and the relative humidity calculated. This method is not accurate in moving air. In still air the layer which is in contact with the metallic surface is in equilibrium; in a breeze the constant renewal of the air near the surface prevents its attaining the dew point until a lower temperature is reached.

The readings of a dew point apparatus are affected by the water vapor given off in the breath of the operator. Less than five grams of water are required to saturate a cubic meter of air at zero centigrade. The average human being gives off 63 grams of water vapor per minute in repose; therefore, the presence of the operator is always a disturbing element in humidity determinations.

The air in contact with a thin metallic surface may be cooled to the dew point by ice water, ether or some other substance. It is assumed that the air within is at the same temperature as that which surrounds the instrument. The average of the temperature at which the film appears, and the temperature at which it disappears, is used as the dew point temperature.

The measurement of humidity by the wet and dry bulb depends upon the relation between the saturation of the air and the evaporation of water. The difference between the dew point and the wet bulb reading bears a constant ratio to the difference in readings between the two thermometers, provided the dry bulb temperature remains constant.

The formula developed for this relationship is given below where P_1 is the vapor pressure at dew point, P_2 the vapor pressure at the wet bulb temperature, t_1 and t_2 the temperatures of the dry and the wet thermometers respectively, B the barometric reading and A a constant depending upon the construction and operation of the instrument.

$$P_1 = P_2 - A\,B\,(t_1 - t_2) \qquad - - - - \text{I}$$

The constants, A and B, have been evaluated for certain conditions and tables made giving the relative humidity.

Certain substances, due to their elongation when exposed to moisture, can be used to give the relative humidity. Human hair, one of the most sensitive, elongates 3/128 of its length in saturated air. Recording hygrometers are made up from bundles of hairs. Regnault (An de chemie et de Physique 3e tom X V, P 141, 1845.) has shown that such instruments not only vary with each other, but that they are not self consistent.

METHOD OF PROCEDURE

Before a comparison between any two methods could be made, some method to be used as a standard had to be chosen. The chemical method, since it is the accepted standard, was first considered. Several determinations of the absolute humidity were made using the approved procedure, with the exception that the aspirator temperature varied half a degree over the hour and a half in which the experiment was conducted. The smallest error found in any determination, calculated from the Smithsonian tables, was 4.2%. Because it was impossible to reduce this error, with the apparatus at hand, and because the author felt this to be a research problem in itself, a secondary standard was chosen.

Because of its acceptance by the United States Weather Bureau, the Sling Psychrometer, with the manipulation recommended by the bureau, was adopted. A wind velocity of

10 feet per second at which the greatest depression of the wet bulb occurs, was adopted. At this velocity the constant A (equation I) is identical for all sizes and shapes of thermometer bulbs. [2]The time of exposure of the wet bulb wick to the wind varies with the wind velocity. Preliminary determinations showed a comparatively steady reading of the wet thermometer at the end of three minutes after the wick was wet with distilled water at room temperature. Determinations showed no appreciable difference in readings when the standard was swung, and when wind of 10 feet per second as measured by an anemometer was blown past it from a fan. This last procedure was used for all comparisons, except the Alluard dew point apparatus.

All thermometers were calibrated and corrections applied to readings. Standard wicks were used on all wet bulb thermometers.

In comparing the hygrodeik with the standard, three different procedures were used. The first was to swing the hygrodeik gently from the arm for three minutes and then read. Sample readings from experiments by this method are given in table 1.

In the second procedure the hygrodeik was read in still air, being protected from any wind by a screen, the anemometer giving no reading. Sample data are given in table 2.

Sample Data for Sling and Hygrodeik

Table 1

Hygrodeik swung from arm.

Sling			Hygrodeik		
Dry Temp. °F.	Wet Temp. °F.	R.H.	Dry Temp. °F.	Wet Temp. °F.	R.H.
84.0	57.2	15.4	83.0	58.8	20.7
84.2	57.5	15.8	83.0	59.1	21.3
84.0	57.9	16.8	82.7	59.7	23.3
83.9	57.8	16.7	82.7	60.0	24.1
83.5	57.5	16.5	82.0	60.1	25.0
83.5	57.4	16.3	82.0	59.5	23.8
83.3	57.4	16.6	82.0	59.5	23.8
83.1	57.7	17.9	82.0	59.7	24.2
83.3	58.4	19.5	82.0	59.2	23.2
83.1	57.7	17.9	82.1	59.1	24.9
	Average -	16.6		Average -	23.4

Sample Data for Sling and Hygrodeik

Table 2

Hygrodeik in still air.

Sling			Hygrodeik		
Dry Temp. °F.	Wet Temp. °F.	R.H.	Dry Temp. °F.	Wet Temp. °F.	R.H.
84.5	60.3	21.2	81.6	62.8	34.2
83.8	60.6	24.3	81.9	62.6	33.0
84.3	61.3	24.5	82.2	63.1	33.8
84.5	61.1	24.0	82.2	63.1	33.8
84.7	61.2	23.8	82.9	63.2	32.3
85.2	61.6	24.4	83.6	64.2	33.6
85.4	61.6	24.1	83.4	64.2	34.1
85.6	61.8	24.2	83.6	64.2	33.5
86.0	62.0	24.0	83.8	64.2	33.1
86.1	62.1	24.1	83.9	65.0	35.2
86.3	62.3	24.1	84.1	64.5	33.2
	Average - 24.1			Average - 33.5	

Finding these results too high, the author placed the hygrodeik in the same wind as the standard. Due to the rapid evaporation, it was found necessary to wet the wick each time, three minutes before reading. Every care was taken to make this procedure identical with the standard. Table 3 shows sample readings.

The hygrodeik contains a self computer by which the relative humidity can be estimated. Table 8 gives mean results for all three procedures.

The second and third procedures for the hygrodeik were also used on the second wet and dry hygrometer, which does not have a self computer. Sample results for still air are given in table 4. Table 5 gives the sample results when read in air moving 10 feet per second. Table 9 gives the per cent of disagreement between this instrument, using these methods, and the standard.

The exhaust psychrometer, used primarily in entomology to measure the humidity in insect cages, employs the wet and dry bulb principle. The air from the cage is drawn through a rubber tube past the thermometers and passed back into the cage, by means of a fan turned by a crank and gear train. The average wind velocity is 460 feet per minute, or 7.6 feet per second. Sample data are given in table 6 and the per cent of error in table 10.

A comparison between the Alluard dew point and the

Sample Data for Sling and Hygrodeik

Table 3

Hygrodeik in wind of 10 ft./sec.

Sling			Hygrodeik		
Dry Temp. °F.	Wet Temp. °F.	R.H.	Dry Temp. °F.	Wet Temp. °F.	R.H.
75.9	60.3	42.2	75.8	61.1	42.7
75.7	60.0	41.7	75.3	61.1	43.7
75.7	60.0	41.7	75.1	61.0	43.8
76.1	60.0	40.4	75.0	61.1	44.4
75.9	60.0	41.3	75.1	61.1	44.1
75.7	60.1	42.0	74.8	61.2	45.4
76.1	60.2	40.8	75.2	61.1	43.9
76.0	59.9	40.4	74.5	61.1	46.3
75.7	58.8	40.9	74.5	61.3	46.9
75.6	59.7	40.8	74.1	61.0	46.8
	Average - 41.2			Average - 44.8	

Sample Data for Sling and Mason Hygrometer

Table 4

Mason Hygrometer in still air.

Sling			Mason Hygrometer		
Dry Temp. °F.	Wet Temp. °F.	R.H.	Dry Temp. °F.	Wet Temp. °F.	R.H.
74.6	64.2	57.0	73.2	66.0	68.4
74.4	63.7	55.6	72.8	64.8	65.0
74.1	63.8	56.9	73.0	65.0	65.0
74.3	63.3	54.3	73.0	64.6	63.4
74.0	64.2	58.4	73.4	65.3	65.0
74.3	63.9	56.7	73.2	65.3	65.6
74.1	63.8	56.9	73.4	65.4	65.3
73.5	64.5	63.5*	73.4	66.2	68.6
74.1	63.7	56.8	73.2	65.4	66.0
73.9	63.7	57.8	73.4	65.3	65.0
	Average - 56.7			Average - 65.7	

* discarded.

Sample Data for Sling and Mason Hygrometer

Table 5

Mason Hygrometer in wind 10 ft./sec.

Sling			Mason Hygrometer		
Dry Temp. °F.	Wet Temp. °F.	R.H.	Dry Temp. °F.	Wet Temp. °F.	R.H.
75.9	61.0	42.2	75.1	60.9	43.5
75.7	60.7	41.7	74.4	60.5	44.3
75.7	60.7	41.7	74.9	60.9	44.0
76.1	60.7	40.4	75.3	61.2	44.0
75.9	60.7	41.3	75.3	60.9	43.1
75.7	60.8	42.0	74.5	60.9	44.9
76.1	60.8	40.8	75.0	60.9	43.7
76.0	60.6	40.4	74.6	60.6	44.0
75.7	60.5	40.9	74.6	60.7	44.0
75.6	60.4	40.8	74.4	60.6	44.2
	Average - 41.2			Average - 44.0	

Sample Data for Sling and Exhaust Psychrometer

Table 6

Exhaust Psychrometer.

Sling			Exhaust Psychrometer		
Dry Temp. °F.	Wet Temp. °F.	R.H.	Dry Temp. °C.	Wet Temp. °C.	R.H.
70.7	63.1	65.7	21.5	17.4	67.1
70.8	63.0	65.6	21.1	17.2	67.9
72.4	63.2	59.8	21.8	18.5	73.4
72.3	62.5	57.3	21.4	17.9	71.4
72.3	63.3	60.5	21.6	18.4	73.9
71.7	63.1	61.6	21.6	17.4	66.2
72.4	63.8	62.2	21.8	17.7	67.0
73.0	63.7	60.8	21.9	18.1	69.5
73.1	64.2	61.4	22.1	18.9	74.5
72.3	64.7	66.0	21.9	19.3	78.7*
	Average - 62.1			Average - 71.0	

* discarded.

standard is given in table 11. Commercial ether was used to cool the air. The standard was swung by hand and care was taken to keep the air stationary near the Alluard apparatus. Because of the difficulty of seeing the film when it first appeared, the telescope method was abandoned and a paper mask worn over the face was used, the thermometers being read close up. Sample data are given in table 7.

The two instruments containing hairs were set with the standard and read daily. The readings and deviations for each are given in tables 12 and 13.

Conclusions from Results

Conclusions from the Data for the Sling and Hygrodeik

Table 8

Hygrodeik

17%	rel. humidity	reads	41.0%	high,	slung from arm
24%	" "	"	38.6%	"	in still air
44%	" "	"	19.3%	"	" " "
57%	" "	"	13.7%	"	" " "
26%	" "	"	9.4%	"	wind at 10 ft. per sec.
41%	" "	"	8.7%	"	" " " " " "
62%	" "	"	1.6%	"	" " " " " "

Sample Data for Sling Alluard

Table 7

Alluard

Sling			Alluard		
Dry Temp. °F.	Wet Temp. °F.	R.H.	Dry Temp. °C.	Wet Temp. °C.	R.H.
76.6	61.1	40.6	24.4	12.1	56.8
75.3	60.6	41.2	23.9	9.8	52.0
74.5	60.0	42.3	23.7	10.2	53.6
73.8	60.0	44.4	23.5	9.2	51.3
73.9	60.2	44.8	23.6	9.0	50.7
75.0	60.5	43.0	23.9	9.6	51.7
75.4	60.6	42.0	24.0	13.5	61.8*
75.5	60.6	41.8	24.0	9.4	50.7
75.5	60.6	41.8	24.3	11.4	55.1
75.2	60.6	42.4	23.9	8.5	49.0

* discarded.

The hygrodeik operating in a wind of 10 feet per second agrees with the standard inside of experimental error in the region of 62% relative humidity. Hence the hygrodeik is reliable for this region when in a wind of 10 feet per second. The hygrodeik reads approximately 9% high in the regions of 26% and 41% of relative humidity which is 5% greater than the difference between any reading and the mean of the same set of ten.

When the hygrodeik is used in still air, as the relative humidity changes from 24% to 57%, the error changes from 38.6% to 13.7%. Therefore, in this region the error of the hygrodeik varies inversely as the relative humidity. It is obvious that in this region the hygrodeik in still air does not give accurate readings.

In the region of 24% to 26% relative humidity the error was reduced from 38.6% to 9.4% when the position of the hygrodeik was changed from still air to one in a wind of 10 feet per second. In the region of 17% to 26% relative humidity an error of 41%, when swung from the arm, was reduced to 9% when in a wind of 10 feet per second.

The hygrodeik, to give the minimum error, should be operated in an air current of 10 feet per second which is impossible without the assistance of a fan.

In the relative humidity region from 17% to 62% the self computing device gives results approximately 2% higher than those obtained from the table using the hygrodeik as a simple wet and dry bulb hygrometer. This error is less than the difference between individual hygrodeik readings in a set of 10 determinations.

The hygrodeik thermometers were mounted on a sling frame and manipulated in parallel with the standard. Computations from the readings taken showed that the improvised sling gave the same percentage of error as that read from the same thermometers on the hygrodeik frame. Therefore, this error cannot be due to the proximity of the frame.

Conclusions from the Data for the Sling and Mason Hygrometer

Table 9

Mason Hygrometer

26%	rel. humidity	reads	11.6%	high	wind at 10 ft. per sec.
41%	"	"	6.7%	"	" " " " " "
63%	"	"	.2%	"	" " " " " "
27%	"	"	40.0%	"	when in still air
44%	"	"	21.0%	"	" " " "
57%	"	"	15.8%	"	" " " "

In the region of 63% relative humidity the Mason hygrometer, when operated in a wind of 10 feet per second, agreed with the standard within experimental error.

In the region of 26% relative humidity this instrument reads 11.6% high which is 7.8% greater than the difference between any reading for a set of ten determinations and their mean. At 41% relative humidity the error was 6.7% high which is 6% greater than the difference between any reading for a set of ten determinations, and their mean. This indicates that in these regions there is a notable error in the humidity as found by the Mason hygrometer operated by this procedure.

As the relative humidity, as indicated by this instrument increases from 27.5% to 57% the error decreased from 40% to 15.8%. This error bears an approximate inverse ratio to the relative humidity. It is obvious that the relative humidity taken by this method would have little value where accuracy is desired.

When placed in a wind of 10 feet per second the error, for still air, is reduced from 40% to 11.6% in the region of 26% relative humidity; from 21% to 7% in the region of 41% relative humidity, and from 16% to a negligible quantity in the region from 57% to 63% relative humidity. In general the Mason hygrometer behaves like the hygrodeik in the relative humidity regions studied. This seems reasonable since they are both wet and dry bulb devices.

Conclusions from the Data for the Sling and Alluard

Table 10

Alluard

At	25.8%	relative humidity	reads	29.1%	high
"	42.4%	"	"	23.3%	"
"	60.0%	"	"	14.4%	"

In the regions studied, the Alluard has an error of about four times the difference between any reading for a set of ten determinations and its mean. This instrument tends to become more nearly correct at the higher humidities but the errors however are so large as to invalidate this method for scientific work.

Conclusions from the Data for the Sling and Exhaust Psychrometer

Table 11

Exhaust Psychrometer

At	25.5%	relative humidity	reads	31.8%	high
"	43.0%	"	"	23.0%	"
"	62.0%	"	"	12.0%	"

In the regions studied the error between the exhaust psychrometer and the standard is about four times the difference between any reading in a set of ten determinations and its mean. These results indicate that humidities given by this instrument may be in error from 12% to 30%, in the relative humidities studied.

Conclusions from the Data for Sling and Hair Hygrometers

Table 12

Hair Hygrometer

17% - 47% rel. humidity, ave. dev.	2.3	first 15 days
17% - 47% " " " "	1.6	15 to 28 days

Table 13

Hair Hygrograph

17% - 47% rel. humidity, ave. dev.	0.8	first 15 days
17% - 47% " " " "	5.9	15 to 26 days

The two hair hygrometers tested did not agree each with the other. The hair hygrometer became more nearly correct after the first ten days while the error in the hygrograph increased.

GENERAL CONCLUSIONS

The wet and dry bulb hygrometers, the hygrodeik and the Mason hygrometer, check with the Sling as standard only in a wind velocity of 10 feet per second in a relative humidity region of 62%.

All other methods studied, the Alluard, the exhaust hygrometer and the hair hygrometer give results so much in error that they are unsuited for precision work. The wet and dry bulb hygrometers were found unsuited for precision work in relative humidity regions below 62%.

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