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Technical Report

Humidity Measurement Comparison Tests

Dew Point Hygrometer
vs.
Wet Bulb Psychrometer

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Abstract

A series of comparison tests were made to characterize and quantify causes of differences in results between the dew point hygrometer and the wet bulb psychrometer methods of measuring humidity. The EPA Laboratory is implementing the dew point hygrometer method in the Light Duty test cells. Tests were necessary in order to identify any potential impact on test results. This study provides supportive data to address the test procedure comparability aspects of EPCA.

The results of these tests indicate that the pyschrometer specific humidity indication will average approximately 5 gR/lb higher than the dew point hygrometer. The major causes of this error are the wick water temperature and ventilating air velocity.

Introduction (Background)

The Energy and Policy Conservation Act of 1975 and letters dated February 1980 from the EPA Administrator to Ford and GM establishes policy that mandates the EPA laboratory to use procedures for testing vehicles for fuel economy that are the same as those utilized for the 1975 model year. Provisions were made by Congress to allow test procedure changes that would improve the test accuracy and reduce variability of emission and fuel economy measurements as long as there is no significant impact on Corporate Average Fuel Economy (CAFE). However, the sensitive nature of any such change necessitates a quantification of the results of the action.

The EPA laboratory has been in the process of developing and installing new ambient monitoring instruments in the Light Duty test cells that will be interfaced to the real time Laboratory Computer System (LCS). One of these instruments, the dew point hygrometer will replace the wet bulb psychrometer for measuring humidity. Studies performed and reported in December 1980, data samples taken from official tests in 1982, and recent direct comparison tests indicate differences in the results of these two measurement methods. The comparisons showed the wet bulb psychrometer humidity results to be approximately 5 grains higher than the dew point results. The study of 1980 indicated that the major differences were caused by the wick water temperature and low air velocity of the psychrometer. In order to provide additional confirmatory and supplemental data that relate to these measurement differences, another series of comparison tests was designed and performed. This paper reports the results of that study.

Theory of Operation

The wet and dry bulb psychrometer and the condensation type dew point indicators are two distinctly different methods of measuring humidity.

The basic form of a wet and dry bulb psychrometer uses two thermometers. The bulb of one thermometer is covered with a moistened wick and is called the wet bulb. The bulb of the other is left bare and is referred to as the dry bulb. The accuracy of humidity measurements requires these thermometers to be closely matched. The evaporation of water from the moistened wick of the wet bulb thermometer produces a lowering in temperature. The thermometer may be ventilated by a sling or forced air circulation. Ventilation should be provided to the wick at a minimum velocity of 900 feet per minute. (See Reference 4-NBS Circular 512).

Using the reading of the two thermometers and the barometric pressure, the humidity, specific and/or relative, can be determined. Specific humidity is calculated by determining the saturation pressure of water vapor at the wet bulb temperature by a least squares fit of Keenan and Keyes steam table and the partial pressure of water vapor at the dry bulb temperature. These are determined by equations as recommended by Wexler and Greenspan in the NBS paper "Vapor Pressure Equation for Water in the Range of 0 to 100°C" and by Eric Zellin in "Procedures for Calculating Humidity" (See Reference).

The condensation dew point method of measuring humidity is a fundamental technique by which a surface is cooled until a dew layer is formed on that surface. The temperature of the surface at that point is called dew point temperature. The dew point temperature is defined as that temperature to which water vapor must be reduced to obtain saturation vapor pressure or a relative humidity of 100 percent. The unit discussed in this paper is an optical condensation type dew point meter. With this unit a sample of air is drawn across a mirror surface at a flow rate of 2.0 SCFH. The mirror is cooled by thermoelectric heat pump action until a dew layer is formed by the condensation of moisture from the sample air. A beam of light from an LED is directed at the mirror which reflects the light to a photo cell. The photo cell detects the light and produces a corresponding current. When the dew layer is formed, the reflectance of light will sharply decrease causing a decrease in photo current. The system is designed to control the dew layer in a feedback contol loop by heating or cooling of the mirror surface. This heating or cooling is referenced to a 40 percent (40%) decrease in photo current level from a clean dry mirror condition. The temperature of the mirror surface is measured by a platinium RTD thermometer with a specified accuracy of ± 0.4°F, is displayed on a digital meter and is read by the Laboratory Computer System. This reading is the dew point temperature and is used to calculate the specific humidity from the partial pressure of water vapor at that temperature and the barometric pressure.

For the data analysis of this experiment, the dew point has been used to represent the correct humidity. The dew point was verified by an ice bath closed loop coil technique that produces a dew point of 32°F.

Test Plan

A series of 32 test sequences was developed for various combinations of conditions to characterize the differences between the wet bulb and the dew point humidity measurement methods. Psychrometer air velocity, wick exposure, water temperature and level, and humidity levels were varied in the test plan. The test set up consisted of a Sargent Welch psychrometer frame, a flexible hose, and adapter chamber, the laboratory ventilation system with an adjustable damper, a mercury thermometer (certified accurate and readable to ± 0.2°F), a cotton wick, a mercury thermometer (readable to 0.5°F) matched to the certified version, a type J thermocouple and recorder, a Thermo Systems Model 1650 heater wire anemometer, and a General Eastern Model 1200 APS dew point meter. The equipment was set up in the Gas Blending room (See Figure 1).

Simultaneous humidity measurements were made using the two methods under the combinations of conditions as shown on Table C. Sock up means the wet bulb was entirely covered in the tube. Sock down means the sock was moved down on the thermometer 3/4" from the top of the tube. Test conditions included the reservoir full, and 1/2 full, the wick water temperature at ambient and within ±2.0 degrees F from the wet bulb temperature, and with low (450 FPM), medium (700 and 900 FPM) and high (1300 and 1500 FPM) air velocities of the psychrometer. The points where the wick water was below the wet bulb temperature were later deleted from the data.

The readings were taken by two operators. The readings made by SF were taken with a magnified jewelers glass. Measurements were also taken of four room humidity settings using ambient water temperature, air velocity at 900 FPM, reservoir full, and the sock completely covering the thermometer inside the tube. These specific humidity levels were approximately 80, 70, 50 and 35 grains of water per pound of dry air. The first set of tests were made on 11/30/82 and 12/1/82 and consisted of six readings each. A set of confirmatory tests were run on 12/1/82 and 12/2/82 and consisted of three readings for each condition. The room humidity level comparisons were run on 12/3/82 and 12/9/82. All readings taken were approximately 2 minutes apart in each sequence.

Discussion (Summary of Test Results)

The attached tables show the results of the tests. Table A shows the test plan overview and includes the average humidity at each set of indicated conditions. Table B shows the average effect of each parameter. The average was determined from all the pairwise differences involving the parameter. The original and confirmatory tests indicate the following:

- Increasing the air velocity from 450 to 1500 feet per minute in steps of 300 feet per minute decrease the measurement difference at both the cold and ambient water temperature an average of 1.29 gr/lb.

- Decreasing the water temperature from ambient to the wet bulb temp or up to 2° above decreases the differences at the air velocities tested an average of 3.55 gr/lb.

- With all other conditions at optimum (sock up, standard humidity level, and full reservior), increasing the air velocity to the recommended level or decreasing the water temperature to the wet bulb temperature) separately will cause a decrease in the error but will not eliminate it completely until all three conditions are optimized.

- As shown in Table B, total bias caused by low velocity, ambient water, low reservoir and sock not completely covering the bulb in the tube can cause the wet bulb to read about 7 grains/lb. higher than the dew point. The typical bias would be at the lower air velocity, ambient temperature water, and a half full reservior. At these conditions the psychrometer reading would average 5.2 grain/lb. higher.

- Although the test did not address this point, type J thermocouple accuracy tolerance can introduce an additional ± 2.0 grain error. Since the wet bulb sensitivity is ±2.5 gr./lb. per ±1°F, an accuracy spec of ±.75°F on Type J could cause a 2.0 gr./lb. error. Likewise, a ±0.4°F technician integration error would introduce a ±1.0 gr./lb. error.

- As Table C shows the majority of these tests were run on three consecutive days with room humidity level checks being made on 12/9/82. The majority of the original tests were read by Steve Pfeiffer while the majority of the confirmatories were read by Sherm Funk. It appears that after a plot analysis and a later confirmation test the wet bulb data on lines 7, 8, and 9 were mis-read low by 1°. These points were adjusted on Table A and shown in parenthesis, but were deleted from the calculated values of Table B and the plots on Figure 2.

One of the difficult parts of this experiment was to maintain the temperature in the reservior to recommended levels (+2.0°F from the wet bulb temperature). Crushed ice was mixed with the water and as the ice melted the water temperature would rise. It was necessary to take six readings two minutes apart during the time the water temperature was in the four degree window. It was found that if more ice was used the temperature rise was considerably slower. NBS recommends that the water temperature be maintained at or slightly above the wet bulb temperature, (See Reference, NBS circ. 512).

Some points were read where the wick water temperature was below the wet bulb temperature. After the data were plotted, the results showed that at these conditions the psychrometer read lower than the dew point meter. If the dew point meter is considered the accurate instrument, the results agree with the NBS statements. This phenomena was taken into account and these points were deleted from our reported data.

Conclusions/Recommendations

This experiment demonstrates and quantifies that the typical conditions of our psychrometer (low air velocity, ambient temperature water and less than full reservior) cause a positive bias of about 5 grains. If the sock is down or a contaminated wick condition is added, the bias increases to about 7 grains. Furthermore, the thermometer calibration and reading error could increase the bias to 10 grain/lb. or more. These tests explain the causes for the levels of error that have been seen in previous comparisons and reaffirms the humidity report of December 1980.

- The dew point method is a very accurate and reliable technique for measuring humidity. The dewpoint hygrometer units installed in this laboratory use the fundamental method of condensation, and incorporates such measures as an alarm for excessive contamination, automatic correction circuitry, a highly accurate platinium RTD thermometer for surface temperature measurement, and a mirror surface self-cleaning capability. These features eliminate the inherent characteristics of the wet bulb psychrometer that can result in a biased humidity measurement. In addition, the use of a dew point temperature is a more direct means of calculating humidity as opposed to wet bulb and dry bulb.

Recommendations

- It is recommended that the dew point meter be implemented as the method to measure humidity and that they replace the wet bulb/dry bulb psychrometer and the Esterline Angus recorders in the Light Duty test cells.

- It is recommended that the Laboratory Computer System (LCS) be used to collect and process the output data from these units and that the data be used to set room humidity levels and to calculate NOx correction factor for official emission tests.

References

1. EPA Administrator's Letters to General Motors and Ford, Subject: Impact of Test Procedure Changes on Corporate Average Fuel Economy (CAFE), February 19, 1980.

2. EPA Technical Report, Test Cell Humidity Investigation Report, Sherman D. Funk, April 17, 1980

3. EPA Technical Report, Assessment of Test Cell Humidity Measurement and Control, EPA-AA-EOD-80-13, Sherman D. Funk, December 1980.

4. NBS Circular 512, Methods of Measuring Humidity and Testing Hygrometers, A. Wexler, W.G. Brombacher, Sept. 28, 1951.

5. Vapor Pressure Equation for Water in The Range of 0 to 100°C. A Wexler and L. Greenspan, NBS, Feb. 19, 1971.

6. EPA Memo, Comparison of Humidity Correction Factor Procedures, Eric Zellin, May 31, 1973.

7. EPA Internal Paper, A Procedure for Calculating Humidity, Eric Zellin, July 1975.

8. Instruction Manual Dew Point Meter 1200 APS, General Eastern Corp., June 1979.

9. EPA Internal Document, Technical References and Procedures for Calculating Humidity, Eric Zellin, January 1983.

Attachments

TABLE A: HUMIDITY DIFFERENCES
RELATIVE TO VARIABLE PARAMETERS
(WET BULB - DEW POINT) (GR/LB)

	TWP -0, +2°F.					75 + 2°F.				
AIR VEL	1	2	3	4	5	6	7	8	9	
FPM	450	700	900	1300	1500	450	700	900	1300	1500
SOCK UP RES ½ FULL ORIGINAL N = 6	+ 1.6		+ 0.4		+ 0.04	+ 5.0		+ 4.0		+ 2.6
CONFIRM N = 3		+ 0.2				+ 5.4	+ 4.6	+ 3.6	+ 3.0	
SOCK UP RES. FULL ORIGINAL N = 6	+ 0.9		+ 0.2			+ 1.4		+ 0.6		- 0.1
						(+ 6.0)*		(+ 5.2)*		(+ 1.5)*
CONFIRM N = 3	+ 1.4		- 0.3	+ 0.3		+ 4.6	+ 4.5	+ 4.3	+ 3.0	
SOCK ½ DOWN RES. FULL ORIGINAL N = 6						+ 8.0		+ 6.4		+ 4.8
HUMIDITY ORIGINAL N = 6 GR/LB 78.6								+ 2.2		
69.8								+ 2.6		
52.4								+ 1.9		
30.2								+ 1.8		

* NOTE: DATA IN PARENTHESES ARE CORRECTED FOR A POSSIBLE ONE DEGREE READING ERROR OF WET BULB.

TABLE B - ANALYSIS OF PAIRED DIFFERENCES

PARAMETER CHANGED	RELATED PAIRED DIFFERENCES	AVERAGE SHIFT GR/LB
DECREASE H_2O TEMP (75 - WB)	(-3.4*, -3.6*, -4.4, -3.2, -4.0, -2.7)	-3.55
INCREASE AIR VELOCITY BY 500 fpm	(-1.2, -1.0, -1.4, -1.7, -0.3, -1.5, -1.6, -1.6)	-1.29
RESERVOIR FILLED (1/2F - FULL)	(-0.5, -0.2, -0.4, -0.7, 0.0)	-0.36
SOCK POSITION DOWN - UP	(-3.4, -2.2, -1.8)	-2.50
EXAMPLE: * -3.4 = 1.6 - 5.0 (See Table A) @ 450 fpm * -3.6 = .4 - 4.0 @ 900 fpm, etc.		
TOTAL BIAS	LOW VEL, AMB H_2O, 1/2 FULL, SOCK DOWN	-7.7
TYPICAL BIAS	LOW VEL, AMB H_2O, 1/2 FULL, SOCK UP	-5.2
TYPE J T/C ERROR		±2.0
MANUAL INTEGRATION ERROR		±1.0
MAXIMUM BIAS		10.7

TABLE C

WET BULB VS DEW POINT HUMIDITY CORRELATION TESTS 12-14-82

SEQ#	1982 DATE	TIME	OPER INIT.	SOCK	RES.	H_2O TEMP	AIR VEL FPM	BARO. HG	DB°F	WB°F	DP°F	WB(G)	DP(-)	Δ(G)	COMM.	Series	# OF POINTS TAKEN (DELETED)
								← APPROX.	AVERAGE →			SPEC. HUM AVG.		WB-DP			
1	11-30	10:10A.M.	SP	UP	½ FULL	60°	450	29.03	73.1	59.1	40.5	53.3	51.7	+1.6			
2	11-30	10:12A.M.	SP	UP	½ FULL	60°	900	29.03	73.8	59.5	49.3	54.0	53.6	+0.4			
3	11-30	10:13A.M.	SP	UP	½ FULL	60°	1500	29.03	73.8	59.3	49.4	53.7	53.6	+.04			(3)
4	~~12-1~~	~~10:3A.M.~~	~~SP~~	~~UP~~	~~FULL~~	~~60°~~	~~1500~~	~~29.04~~	~~73.9~~	~~59.6~~	~~50.0~~	~~54.8~~	~~55.0~~	~~-0.2~~		FIRST SET (SERIES OF 6)	(6)
5	12-1	11:05AM	SP	UP	FULL	60°	900	29.03	73.7	59.8	50.5	56.2	56.0	+0.2		FIRST SET (SERIES OF 6)	(3)
6	12-1	11:32A.M.	SP	UP	FULL	60°	450	29.04	73.4	60.1	50.9	57.8	56.9	+0.9		FIRST SET (SERIES OF 6)	(1)
7	12-1	12:40P.M.	SP	UP	FULL	74°	450	29.03	74.0	60.3	50.4	57.3	55.9	+1.4	CORR. → +6.0	FIRST SET (SERIES OF 6)	
8	12-1	1:25P.M.	SP	UP	FULL	74°	900	29.03	74.3	60.1	50.3	56.2	55.6	+0.6	+5.2	FIRST SET (SERIES OF 6)	
9	12-1	1:57PM	SP	UP	FULL	74°	1500	29.03	74.3	60.0	50.3	55.7	55.8	-0.1	+4.5	FIRST SET (SERIES OF 6)	
10	12-1	2:35PM	SF	UP	½ FULL	74°	1500	29.03	74.5	60.7	50.4	58.4	55.8	+2.6		FIRST SET (SERIES OF 6)	
11	12-1	3:07PM	SF	UP	½ FULL	74°	900	29.03	74.5	60.8	50.1	59.0	55.0	+4.0		FIRST SET (SERIES OF 6)	
12	12-1	3:21PM	SF	UP	½ FULL	74°	450	29.03	74.6	61.0	50.0	60.0	55.0	+5.0		FIRST SET (SERIES OF 6)	
13	12-2	9:15A.M.	SF	UP	½ FULL	75°	450	29.30	74.0	60.9	49.9	59.7	54.3	+5.4		CONFIRMATORY (SERIES OF ?)	
14	12-2	9:30A.M.	SF	UP	½ FULL	75°	700	29.30	74.0	60.8	50.0	59.1	54.5	+4.6		CONFIRMATORY	
15	12-2	9:44AM	SF	UP	½ FULL	75°	900	29.30	74.0	60.6	50.0	58.2	54.6	+3.6		CONFIRMATORY	
16	12-2	10:25AM	SF	UP	½ FULL	75°	1300	29.30	74.0	60.5	50.1	57.7	54.7	+3.0		CONFIRMATORY	
17	12-2	10:45A.M.	SF	UP	FULL	75°	1300	29.30	74.0	60.6	50.2	57.9	54.9	+3.0		CONFIRMATORY	
18	12-2	10:54AM	SF	UP	FULL	75°	900	29.30	74.0	60.9	50.3	59.5	55.2	+4.3		CONFIRMATORY	
19	12-2	11:10A.M.	SF	UP	FULL	74.5°	700	29.30	74.0	61.0	50.3	59.9	55.4	+4.5		CONFIRMATORY	
20	12-2	12:54AM	SF	UP	FULL	73.5	450	29.26	74.5	61.3	50.6	60.5	55.9	+4.6		CONFIRMATORY	
21	12-2	1:24AM	SF	UP	FULL	59.0	450	29.26	73.5	59.7	50.0	56.4	55.0	+1.4		CONFIRMATORY	(2)
22	12-2	1:32P.M.	SF	UP	FULL	62.0	900	29.26	74.0	60.0	50.4	55.1	55.4	-0.3		CONFIRMATORY	
23	12-2	1:44P.M.	SF	UP	FULL	59.0	1300	29.26	74.0	60.0	50.5	55.8	55.5	+.3		CONFIRMATORY	(1)
24	~~12-2~~	~~2:06PM~~	~~SF~~	~~UP~~	~~½ FULL~~	~~58.0~~	~~1300~~	~~29.26~~	~~74.0~~	~~59.5~~	~~50.7~~	~~54.0~~	~~56.0~~	~~-2.0~~		CONFIRMATORY	(3)
25	12-2	2:16PM	SF	UP	½ FULL	63.0	700	29.26	74.0	60.2	50.8	56.5	56.3	+0.2		CONFIRMATORY	
26	12-2	2:36PM	SF	DOWN	FULL	73.0	450	29.26	74.3	62.0	50.8	64.3	56.3	+8.0		SOCK DOWN	
27	12-2	2:42PM	SF	DOWN	FULL	73.0	900	29.26	74.5	61.7	50.6	62.3	55.9	+6.4		SOCK DOWN	
28	12-2	2:47PM	SF	DOWN	FULL	73.0	1500	29.26	74.5	61.4	50.7	61.0	56.2	+4.8		SOCK DOWN	
29	12-3	9:16AM	SF	UP	FULL	73.5	900	29.26	74.4	65.3	59.7	80.8	78.6	+2.2		HUM. LEVEL CHECK	
30	12-9	9:32A.M.	SP	UP	FULL	74.5	900	29.80	74.7	64.2	57.1	72.4	69.8	+2.6		HUM. LEVEL CHECK	
31	12-9	12:15P.M.	SP	UP	FULL	74.5	900	29.80	74.4	60.2	49.4	54.3	52.4	+1.9		HUM. LEVEL CHECK	
	12-9	1:00P.M.	SP	UP	FULL	74.5	900	29.80	74.6	55.0	35.2	32.0	30.2	+1.8		HUM. LEVEL CHECK	

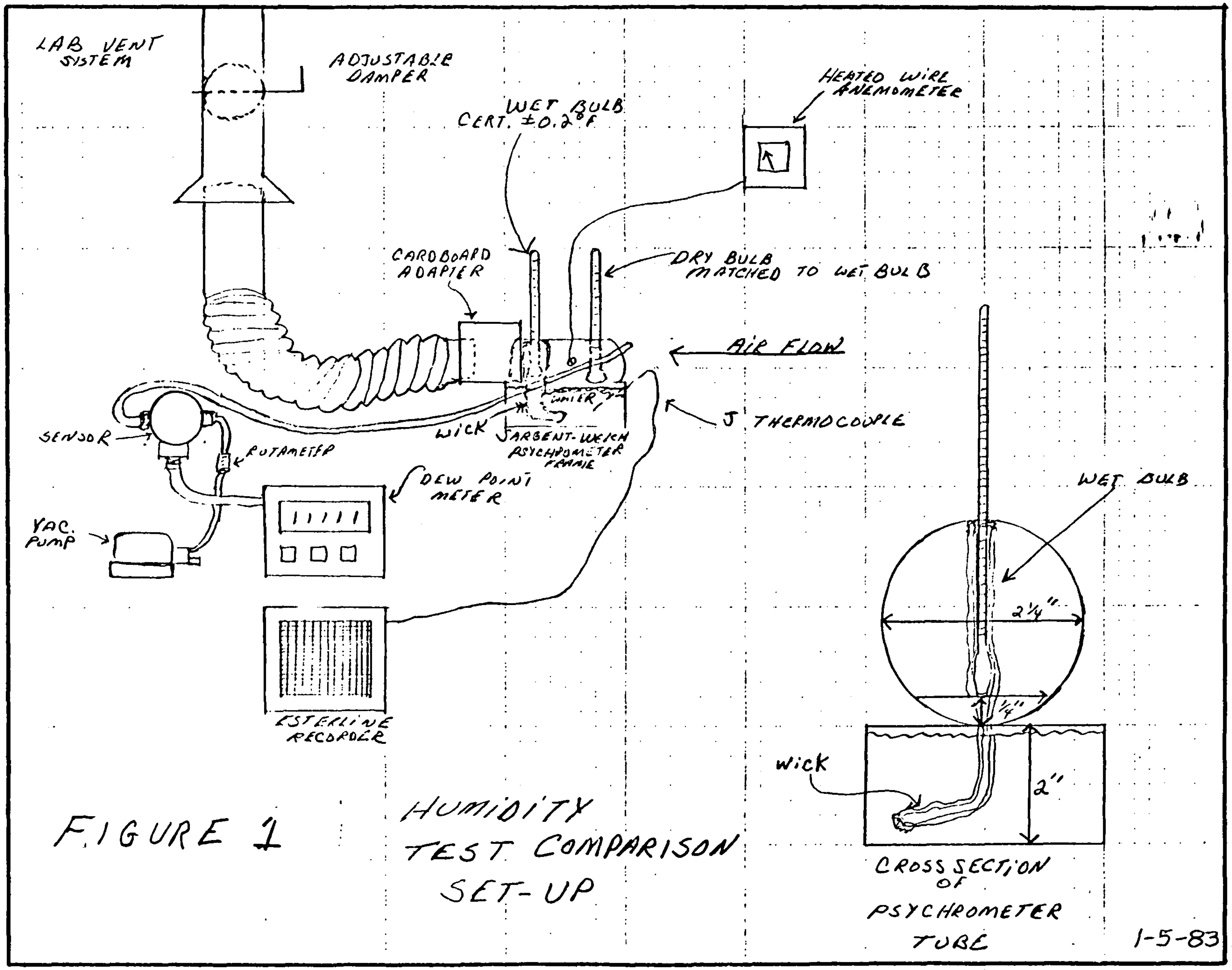

FIGURE 1 HUMIDITY TEST COMPARISON SET-UP

FIGURE 2 - FACTORS AFFECTING PSYCHROMETER ACCURACY