American Industrial Hygiene Association Journal

ISSN: 0002-8894 (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/aiha20

The effect of extreme humidity and temperature on gas detector tube performance

CHARLES S. McCAMMON , WILLIAM E. CROUSE & HERBERT B. CARROLL

To cite this article: CHARLES S. McCAMMON , WILLIAM E. CROUSE & HERBERT B. CARROLL (1982) The effect of extreme humidity and temperature on gas detector tube performance, American Industrial Hygiene Association Journal, 43:1, 18-25, DOI: 10.1080/15298668291409307

To link to this article: https://doi.org/10.1080/15298668291409307

Five replicate samples of each of two brands of detector tubes were tested at two concentrations (at the current OSHA standard and at 2 times the standard) under four different environmental conditions of temperature and humidity for carbon monoxide, carbon dioxide, nitrogen dioxide, nitric oxide, hydrogen sulfide and formaldehyde. Each tube was read by three different observers. An analysis of variance was used to statistically determine the magnitude of biases due to humidity and temperature. Both humidity and temperature caused increases in the coefficient of variation of certain tubes from different manufacturers.

The effect of extreme humidity and temperature on gas detector tube performance

CHARLES S. McCAMMON, Jr., WILLIAM E. CROUSE[A] and HERBERT B. CARROLL, Jr.[B]
U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health, Division of Surveillance, Hazard Evaluations, and Field Studies; [A]Division of Technical Services, Cincinnati, OH; [B]U.S. Department of Energy, Bartlesville Energy Research Center, Production Research Division, Bartlesville, OK

introduction and background

Under the Occupational Safety and Health Act of 1970, the National Institute for Occupational Safety and Health (NIOSH) has the responsibility of recommending sampling and analytical methods of suitable accuracy for making measurements of workers' exposure to toxic contaminants. Similarly, under the Federal Mine Safety and Health Act of 1977, the Secretary of Health, Education, and Welfare has the responsibility of recommending measurement equipment to be used in monitoring worker exposure in mines and milling operations.

On May 8, 1973, the Department of Health, Education and Welfare issued Title 42, Code of Federal Regulations Part 84 for the certification of gas detector tube units. This regulation was issued under authority of the Occupational Safety and Health Act of 1970. In the latter part of 1973, NIOSH was contacted by officials of the U.S. Bureau of Mines with the message that the detector tube certification program was not stringent enough and that certified detector tube units could not be used in the adverse environmental conditions of coal mines. The Bureau of Mines requested that NIOSH incorporate very stringent temperature and humidity testing in the certification program to assure that certified tubes could be used in mines for enforcement activities.

If the request of the Bureau of Mines was to be implemented and detector tubes tested over extremes of temperature and humidity with the same precision and accuracy requirements, the results would be that: 1) the certification of a detector tube unit would require much more time and money, and 2) many perfectly good detector tube units probably would fail the certification. The reason for this latter statement is that detector tube reactions are temperature and humidity sensitive and these limitations are clearly stated by the manufacturers. However, in most industrial situations the temperature and humidity is at a tolerable level and the majority of the detector tube units, even those which are sensitive to temperature and humidity, are not adversely affected. This is not true in a coal mine, where the temperature is typically about 60° F and the air is saturated with water (95-100% RH) or in a metal mine, where the temperatures may exceed 110° F.

In order to respond to the Bureau of Mines' request, NIOSH planned a testing program to determine exactly how detector tubes were affected by adverse environmental extremes. This program tested currently available detector tubes for seven different contaminants which the Bureau of Mines wished to monitor in mines over extremes of temperature and humidity. At the end of this test program, it was believed recommendations could be made as to the advisability of including this type of environmental testing in the certification program.

experimental protocol

An interagency agreement was signed with the Bureau of Mines to have the Production Research Group at the Bartlesville Energy Research Center conduct the testing of the detector tubes. It was decided that the two brands of detector tubes most often used by the Bureau of Mines (of the four major manufacturers — see below) would be tested for the following seven contaminants: carbon monoxide (CO), carbon dioxide (CO_2), nitric oxide (NO), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), hydrogen sulfide (H_2S) and aldehydes (formaldehyde as test gas). Each contaminant would be tested at two different concentrations (at the Occupational Safety and Health Administration (OSHA) Federal Standard and at twice the standard) and four different environmental conditions.

Mention of company name or product does not constitute endorsement by the National Institute for Occupational Safety and Health.

detector tube manufacturers and distributors

Bendix Corporation (Gastec Distributors)
Lewisburg, West Virginia

Mine Safety Appliances Company
Murrysville, Pennsylvania

National Draeger, Incorporated
Pittsburgh, Pennsylvania

Matheson Gas Products (Kitagawa Distributors)
Lyndhurst, New Jersey

The environmental conditions tested were:

I. 40 °F and 20% relative humidity
II. 120 °F and 20% relative humidity
III. 75 °F and 50% relative humidity
IV. 75 °F and 90% relative humidity

Under every test condition (e.g., CO at 50 ppm 40 °F and 20% RH) five tubes were exposed. Each exposed tube was read by three different observers as well as by an optical tube reader. The data in this report are concerned primarily with the results of the three observers.

apparatus

detector tubes

The names and model numbers of the detector tubes used in this test are shown below.

test chamber

A controlled temperature-humidity system, containing a test chamber, temperature controls, a dual recording system for wet-and dry-bulb temperatures, and a refrigeration system supplying the cooling coils was utilized to maintain a controlled atmosphere. Chamber atmosphere temperature was controlled in the range of 3 °C to 93 °C, and relative humidity could be reset with a precision of ± 1 °C temperature and ± 2 percent relative humidity.

gas blending system

The gas blending system, composed of gas permeation tubes and standard gas blends, was made for accurate production of atmospheres containing desired contaminants from the low parts-per-million range up to the low percent range.

The permeation tube system was used for calibration purposes as well as a chamber atmosphere maintenance source. Precisely metered streams of dry nitrogen passed over permeation tubes contained in a constant-temperature water bath were mixed with the pure component diffusing from the tube. Gas-flow restrictors and/or flowmeters were used to control the flow of gases such as CO and CO_2 contained in 34-liter stainless steel blend tanks and high-pressure cylinders.

The gas steam from either the calibration blend or permeation tube was diluted with controlled amounts of air or nitrogen and flowed to the stainless steel chamber through 0.64-cm diameter Teflon tubes. Dry nitrogen continually flowed over the permeation tubes when they were not in use.

Each primary instrument was subject to periodic calibrations with known concentrations of the test gas obtained by dynamically blending air with effluent from permeation tubes. The precision with which a desired concentration could be obtained during blending depended upon the reproducibility of setting and flow accuracy of the flowmeters as well as upon the permeation rate. Errors in the flowrate were evaluated by repetitive settings to a given point on the flowmeter and then measuring the resulting flow with a wet-test meter on a soap-bubble meter. Repetitive settings were periodically made at two or three points as the calibration curve was being prepared for the rotometers. The maximum deviation from the average flow was 2 percent and 3 percent for the two rotometers used. This suggests a probable error in setting a concentration level of 3 to 4 percent.

During the course of testing, the permeation rate of each tube was determined gravimetrically. These permeation

Substance of Interest	Detector Tube Number	
	Gastec	Draeger
CO_2	Carbon Dioxide Low Range** Detector Tube No. 2L	Draeger Tube CH23501** Carbon Dioxide Tube 0.1%/a
CO	Carbon Monoxide Low Range** Detector Tube No. 1La	Drager Tube CH25601** Carbon Monoxide 5/c
NO	Nitrogen Oxides (NO & NO_2)** Simultaneous Detector Tube, No. 10	Drager Tube CH31001** Nitrous Fumes (NO + NO_2)a/a
NO_2	Nitrogen Dioxide Low Range** Detector Tube No. 9L	Drager Tube CH30001** Nitrogen Dioxide 0.5/c
SO_2	Sulfur Dioxide Low Range** Detector Tube No. 5La	Drager Tube CH31701** Sulfur Dioxide 1/a
CH_2O	Formaldehyde Detector Tube No. 91	Drager Tube CH26401 Formaldehyde 0.002
H_2S	Hydrogen Sulfide Extra Low Range** Detector Tube No. 4LL	Drager Tube CH29801** Hydrogen Sulfide No. 5/b

**Denotes that tube is certified by NIOSH.

TABLE I
Summary of Analyses of Variance of Humidity Data[A]

Source of[B] Variation	Degrees of Freedom	CO	CO_2	NO	NO_2	SO_2	H_2S	CH_2O
O	2	58.585 (<.001**)	11.428 (<.001**)	9.119 (<.001**)	18.326 (<.001**)	6.720 (.003**)	14.433 (<.001**)	4.098 (.022**)
BO	2	11.903 (<.001**)	1.690 (.191)	2.242 (.113)	0.193 (.826)	6.474 (.003**)	8.484 (<.001**)	2.944 (.061)
HO	2	2.832 (.065)	9.957 (<.001**)	30.698 (<.001**)	1.734 (.183)	0.450 (.645)	3.515 (.035*)	3.663 (.032*)
CO	2	7.456 (.002**)	1.187 (.169)	1.208 (.306)	1.166 (.318)	2.954 (.058)	13.147 (<.001)	2.100 (.132)
BHO	2	4.124 (.020*)	3.947 (.024*)	4.705 (.012*)	0.406 (.673)	6.176 (.004**)	1.718 (.186)	2.001 (.144)
BCO	2	10.282 (<.001)	2.324 (.104)	3.897 (.025*)	1.257 (.291)	3.642 (.031*)	6.761 (.002**)	1.419 (.251)
HCO	2	4.055 (0.21*)	4.176 (.019*)	1.142 (.326)	1.450 (.241)	0.426 (.661)	13.399 (<.001**)	0.051 (.951)
BHCO	2	1.800 (.172)	0.130 (.879)	2.983 (.056)	5.675 (.006**)	3.528 (.034*)	1.120 (.333)	6.164 (.004**)
TO(HBC)Error		.00257	.00160	.00621	.00295	.00213	.00238	.18570
Degrees of Freedom		64	64	64	64	64	64	48
B	1	21.260 (<.001**)	.001 (.992)	393.810 (<.001**)	45.787 (<.001**)	0.120 (.731)	107.410 (<.001**)	3.631 (.066)
H	1	0.027 (.866)	0.194 (.667)	1.484 (.230)	17.773 (<.001**)	203.944 (<.001**)	0.363 (.558)	5.858 (.022*)
C	1	6.265 (.017*)	2.255 (.139)	9.306 (.005**)	116.489 (<.001**)	65.884 (<.001**)	5.046 (.030*)	0.988 (.669)
BH	1	1.996 (1.64)	0.678 (.578)	1.091 (.305)	48.157 (<.001**)	25.742 (<.001**)	4.631 (.037*)	2.693 (.110)
BC	1	10.952 (.003**)	0.933 (.657)	4.291 (.044*)	11.890 (.002**)	1.414 (.242)	0.003 (.955)	1.554 (.223)
HC	1	0.198 (.663)	0.593 (.547)	1.075 (.308)	6.702 (.014*)	3.473 (.068)	1.660 (.204)	4.548 (.041*)
BHC	1	0.042 (.839)	0.008 (.931)	5.221 (.029*)	44.883 (<.001**)	1.755 (.195)	0.035 (.835)	6.532 (.019*)
T(BHC)Error		.01401	.08922	.01180	.01874	.07403	.01582	7.70722
Degrees of Freedom		32	32	32	32	32	32	24

[A] The tabulated values other than the error terms and their degrees of freedom are F-ratios used to test the corresponding source of variation for nullity. P-values are in parentheses. Statistical significance is indicated by: $^*P \leq .04$, $^{**}P \leq .01$. Some significances may be uninterpretable because of higher order interactions.

[B] B = Brands (1) = Gastec, (2) = Drager
C = Concentration (1) = TLV, (2) = 2 x TLV
F = Temperature (1) = 40 °F, (2) = 120 °F (RH = 20%)
H = Relative Humidity (1) = 50%, (2) = 90%
O = Observers 1, 2, 3
T = Tubes 5 random

tubes maintained their rate within 3 percent very consistently until close to the end of the lifetime of the tube.

concentration monitoring

Precise control of the simulated work atmosphere in the test chamber during instrument evaluation required continuous monitoring of the contaminants in the test atmosphere.

CO was measured with an Ecolyzer Carbon Monoxide Analyzer Model 2400 manufactured by Energetics Science, Inc. A 100-ppm CO blend, checked periodically on a long-path IR instrument, was used to calibrate the Ecolyzer.

CO_2 was measured by thermal conductivity with a Chrono-Frac gas chromatograph containing a 1-meter long by 0.63-cm-diameter column filled with 13X molecular sieve. Samples were withdrawn periodically from the chamber and injected into the gas chromatograph. The chromatograph was calibrated after each sample injected by successive injections of a known concentration CO_2 blend.

TABLE IIA
Summary of Analyses of Variance of Temperature Data[A]
Analyses Involving Both Brands

Source of[B] Variation	Degrees of Freedom	Chemical Considered				
		CO	CO_2	NO_2	SO_2	H_2S
O	2	39.734	2.630	14.528	0.155	6.290
		(<.001**)	(.081)	(<.001**)	(.857)	(.004**)
BO	2	22.961	3.008	2.460	0.785	4.814
		(<.001**)	(.057)	(.094)	(.536)	(.011*)
FO	2	4.302	0.231	5.615	3.402	13.820
		(.017*)	(.797)	(.007**)	(.038*)	(<.001**)
CO	2	1.194	0.905	3.610	0.896	1.047
		(.310)	(.586)	(.034*)	(.584)	(.358)
BFO	2	7.252	0.413	5.397	4.733	2.784
		(.002**)	(.670)	(.008**)	(.012*)	(.068)
BCO	2	1.713	1.355	4.600	0.753	1.126
		(.187)	(.267)	(.015*)	(.521)	(.331)
TCO	2	5.014	0.108	7.675	1.115	4.051
		(.010**)	(.898)	(.002**)	(.335)	(.022*)
BFCO	2	10.504	0.131	1.401	3.344	0.220
		(<.001**)	(.878)	(.255)	(.040*)	(.806)
TO(BFC)Error		.00348	.00595	.00273	.00378	.00198
Degrees of Freedom		64	48	48	64	64
B	1	8.147	24.392	76.717	6.307	156.894
		(.008**)	(<.001**)	(<.001**)	(.016*)	(<.001)
F	1	311.506	0.202	108.688	216.861	84.490
		(<.001**)	(.661)	(<.001**)	(<.001**)	(<.001**)
C	1	0.871	0.691	38.618	1.144	10.008
		(.640)	(.581)	(<.001**)	(.293)	(.004**)
BF	1	137.214	1.257	95.811	183.226	4.663
		(<.001**)	(.273)	(<.001**)	(<.001**)	(.036*)
BC	1	12.672	0.002	16.713	2.138	0.186
		(.002*)	(.965)	(<.001**)	(.150)	(.673)
FC	1	3.369	0.288	4.862	7.508	27.098
		(.072)	(.602)	(.035*)	(.010**)	(<.001**)
BFC	1	1.742	1.325	0.079	1.067	.637
		(.196)	(.289)	(.781)	(.309)	(.431)
TO(BFC)Error		.02641	.04775	.02409	.05920	.01771
Degrees of Freedom		32	24	24	32	32

[A] The tabulated values other than the error terms and their degrees of freedom are F-ratios used to test the corresponding source of variation for nullity. P-values are in parentheses. Statistical significance is indicated by: *P ≤ .01. Some significances may be uninterpretable because of higher order interactions.

[B] B = Brands (1) = *Gastec*, (2) = *Drager*
C = Concentration (1) = TLV, (2) = 2 x TLV
F = Temperature (1) = 40 °F, (2) = 120 °F (RH = 20%)
H = Relative Humidity (1) = 50%, (2) = 90%
O = Observers 1, 2, 3
T = Tubes 5 random

Continuous measurement of NO and NO_2 was made with a Thermo Electron Model 14 Chemiluminescent Analyzer. The Model 14 includes a NO_2-to-NO converter for the measurement of NO_2 via the chemiluminescent process. Calibration of the instrument was maintained with known concentrations of NO_2 from permeation tubes and a Matheson NO blend.

H_2S was measured on a flame photometric detector manufactured by Micro Tek Instruments Corp. This instrument was calibrated with known concentrations of H_2S from a permeation tube.

SO_2 was measured with a modified Mast ozone meter manufactured by Mast Development Co. Flows from a calibration blend or a permeation tube were used to calibrate the instrument at the beginning and end of a test series.

CH_2O was measured using the chromotropic acid method. A batch sampling technique was used with this procedure.

testing procedure

After selecting the experimental conditions for a particular test, the chamber temperature and humidity were set, and the tubes to be evaluated placed inside the chamber. The reference instruments were calibrated and connected to the chamber to continuously monitor the chamber contents. After the atmosphere had reached the pre-selected temperature and humidity, the chamber was quickly brought to the proper test gas concentration by injecting calculated volumes of pure components. Then a flow of the proper make-up blend was set such that the monitor instrument displayed a constant chamber concentration.

Testing began after the tubes had been in the chamber at constant temperature and humidity for about 2 hours. Five separate gas detector tubes were used from each detector system at the selected test concentration. The tips were broken off each end of the detector tube, and the proper end was inserted into the sample pump. The sampling cycle was started by making the required number of strokes on the pump and waiting for the time specified by the tube manufacturer after each stroke. As the test atmosphere was drawn through the tube at a controlled rate, a color change indicated the presence of the test gas. The exposed tube was then removed from the chamber through a 3/8-inch port for reading by observers and the optical tube reader.

The exposed tube was first placed in the optical tube reader and a record made of the stain length, then a panel of three observers read the tubes using the scales provided by the manufacturers. The observers read the manufacturer's instructions before the tests began and were unaware of the test gas concentration in the chamber atmosphere until the test was completed.

statistical analysis

The method of analysis of variance was used to investigate possible biases due to humidity and temperature.

The following coding is used in this report to designate the factors used.

Factor	**Levels**
Brands = B	(1) = Gastec, (2) = Drager
Concentrations = C	(1) = TLV, (2) = 2 X TLV
Temperature = F	(1) = 40 °F, (2) = 120 °F (RH = 20%)
Relative Humidity = H	(1) = 50%, (2) = 90%
Observers = O	1, 2, 3
Tubes = T	5 random*

---

*Each set of five tubes were numbered one through five for accounting purposes, not to indicate that the same five distinct tubes were used throughout the experiment.

TABLE IIB
Summary of Analyses of Variance of Temperature Data[A]
Analyses Involving Only One Brand

Source of[B] Variation	Degrees of Freedom for SS	Chemical and Brand Considered NO, Brand 2	CH$_2$O, Brand 1
F	1	194.457	120.745
		(<.001**)	(<.001**)
C	1	1.847	10.692
		(.193)	(.007*)
FC	1	17.087	1.951
		(.001**)	(.188)
TO(FC) (Error for F, C, and FC)		.02670	.03493
Degrees of Freedom		16	12
O	2	12.366	.437
		(<.001**)	(.651)
FO	2	2.977	1.189
		(.080)	(.322)
CO	2	12.806	.552
		(<.001**)	(.583)
FCO	2	2.442	.703
		(.126)	(.505)
TO(FC) (Error for O, FO, CO, FCO)		.00699	.06709
Degrees of Freedom		32	24

[A] The tabulated values other than the error terms and their degrees of freedom are F-ratios used to test the corresponding source of variation for nullity. P-values are in parentheses. Statistical significance is indicated by: *P≤.05, *P≤.01. Some significances may be uninterpretable because of higher order interactions.

[B] B = Brands	(1) = Gastec,	(2) = Drager
C = Concentration	(1) = TLV,	(2) = 2 x TLV
F = Temperature	(1) = 40 °F,	(2) = 120 °F (RH = 20%)
H = Relative Humidity	(1) = 50%,	(2) = 90%
O = Observers	1, 2, 3	
T = Tubes	5 random	

TABLE III
Estimates of the Coefficient of Variation (C.V.) In Percent (Degrees of Freedom of Variances Involved Are In Parentheses)

GAS	Estimate of C.V. at Standard		Estimate of C.V. at 2 X Standard		F^A	Pooled Estimate of C.V.	
CO	9.784	(16)	7.100	(16)	1.378	8.548	(32)
CO_2	14.990	(14)	13.930	(14)	1.076	14.470^B	(28)
NO	8.204	(12)	10.045	(12)	1.224	9.171	(24)
NO_2	7.408	(14)	10.415	(14)	1.406	9.037	(28)
SO_2	13.212	(16)	12.544	(16)	1.053	12.882	(32)
H_2S	9.085	(16)	8.376	(16)	1.171	9.119	(32)
CH_2O	37.391	(9)	37.493	(9)	1.003	37.422^B	(27)

[A] All F-values below are nonsignificant.
[B] The pooled coefficients of variations for CO_2 and CH_2O are too large to meet the accuracy standard for air monitoring.

Temperature and relative humidity were not considered simultaneously as factors in the same statistical analysis, but were analyzed individually in two separate analyses. In one analysis, results at 40 °F and 120 °F were compared holding relative humidity constant at 20%. In the other analysis, 50% and 90% relative humidities were compared holding temperature constant at 75 °F.

When an observation was missing, the calculations were simplified by eliminating all observations with that tube number from the calculations. Unfortunately, this resulted in the elimination of the NO data for Brand 1 and of the CH_2O data for Brand 2 in the temperature analysis.

Past experience indicates gas detector tube data are normally distributed with standard deviations proportional to means. (That is, coefficients of variation are constant — See Table III.) However, if the observations are divided by their respective true means (the optical tube readings), the resulting ratios theoretically have a constant variance for all means when no bias exists. Since homogeneity of variance is assumed in the usual analysis of variance techniques, the analysis presented here was performed on these ratios rather than the actual observations. Barlett's Test, which checks for homogeneity of variances, did not reveal that the ratios tested possessed pronounced heterogeneity of variance except for the case of CH_2O. (In the CH_2O analysis, increasing either the humidity or temperature appears to increase the variance of the Brand 2 ratios.) This violation of assumptions, however, was not severe enough to invalidate the significance obtained on the data. Therefore, no special analysis of variance technique had to be used.

Table I summarizes the results of the humidity analyses and Table II summarizes the results of the temperature analyses. Part A of Table II summarizes the analysis involving both brands and Part B summarizes the analysis for which there was only one brand analysis for each chemical because of missing data.

Table III presents, by concentration, estimates of the coefficients of variation (CV) of the data submitted. These estimates were obtained by pooling the CV's of each cell. The distribution of these pooled estimates is unknown because the CV's are correlated. Further pooling was performed across concentrations because no obvious difference between the concentration CV's exists.

results

Due to the extremely large amounts of raw data generated in the testing phase of the program, only the results of the statistical analysis of the raw data and a summary of these data will be presented.

Table IV summarizes the raw data in terms of percent difference of the detector tube results as compared to the known generated concentration and percent of CV. The percent difference shows the magnitude and direction of the detector tube results while the percent CV measures the precision of the results. The major performance specification required in the NIOSH detector tube certification program is that the tubes have an accuracy of ± 35 percent at ½ the exposure limit and ± 25 percent at 1 to 5 times the exposure limit. All of the tubes tested except the CH_2O tubes have been tested by NIOSH and found to meet the required accuracy limits (i.e. they are certified). Referring back to Table IV, it can be seen that several of these certified tubes gave results outside the certification limit when tested under conditions of extreme temperature and humidity. Of the twelve certified tubes tested, eight gave results outside the accuracy limits.

This section presents findings which were used to support the summary section at the end of this report. Tables I and II yield the following general statements (listed by gases used). The significant biases (with the exception of some biases with no apparent relation to temperature or humidity) were consistent among the three observers. The statements involving the humidity analysis were essentially based on the results summarized in Table I and those relating to the temperature analysis were based on the results listed in Table II.

conclusions

From the data summarized in Table IV, the following conclusions can be made:

TABLE IV
Summary of Percent Coefficient of Variation and Percent Difference*

Brand of Detector Tube	Test Conc. (%)	50% RH, 75 °F		90% RH, 75 °F		20% RH, 40 °F		20% RH, 120 °F	
		% Cov	% Diff	% Cov	% Diff	% Cov	% Diff	% Cov	% Diff
				CARBON DIOXIDE					
Gastec	0.5	14.6	+14.3	11.4	+17.0	10.3	+22.1	5.5	+21.5
	1.0	23.0	+15.8	11.8	+10.7	7.6	+14.0	8.6	+22.8
Drager	0.5	13.6	+15.6	12.4	+27.2**	21.6	+ 0.2	10.8	+ 2.0
	1.0	12.7	+ 6.9	11.9	+ 9.1	11.8	+ 4.7	11.6	-13.8
				CARBON MONOXIDE					
	Conc. (ppm)								
Gastec	51	12.0	+17.9	14.4	+20.1	10.3	+62.8**	26.1	-22.2
	99	9.8	+ 4.9	5.4	+ 8.1	12.0	+51.6**	13.0	-34.0**
Drager	51	7.2	+ 4.3	5.2	- 1.8	7.1	+ 5.7	4.1	- 2.6
	99	8.2	+ 4.7	3.5	+ 2.9	5.0	+22.8	4.7	- 4.1
				NITROGEN DIOXIDE					
	Conc. (ppm)								
Gastec	5.0	6.0	+ 6.0	6.0	+10.0	5.7	+33.3**	13.3	-18.0
	9.8	1.6	+ 0.3	3.8	+52.0**	6.8	+49.5**	5.9	-20.4
Drager	5.0	7.5	-20.0	10.6	-16.0	10.0	-35.3**	10.8	-32.0**
	9.8	12.5	+26.5**	11.9	+ 9.2	16.5	+ 3.1	14.3	- 3.1
				NITRIC OXIDE					
	Conc. (ppm)								
Gastec	25	6.6	-15.2	8.6	-13.0	10.2	-12.5	7.3	- 7.7
	49	13.1	-14.6	13.2	-17.4	—	—	9.9	- 8.6
Drager	25	11.0	+34.9**	12.0	+23.8	16.0	+ 2.0	7.8	+43.4**
	49	6.4	+18.2	12.2	+20.3	13.5	- 9.7	8.8	+66.6**
				HYDROGEN SULFIDE					
	Conc. (ppm)								
Gastec	10	5.1	+18.1	11.4	+11.1	7.7	+30.4**	4.5	- 1.3
	21	6.3	+ 9.6	2.0	+ 9.5	5.8	+ 9.2	5.5	+ 6.7
Drager	10	10.5	-11.0	16.4	- 7.2	13.0	+ 4.3	9.3	-34.0**
	21	11.5	-18.8	5.6	- 9.9	9.3	-15.1	7.4	-32.0**
				SULFUR DIOXIDE					
	Conc. (ppm)								
Gastec	4.9	14.8	- 6.8	12.3	+36.5**	13.5	-10.7	2.0	+ 2.2
	10	17.6	+24.9	5.5	+73.3**	6.3	- 1.3	16.5	- 3.6
Drager	4.9	15.4	-33.1**	14.8	+47.6**	12.8	-57.7**	14.2	+84.6**
	10	14.5	- 2.7	3.5	+108.6**	9.5	-52.2**	28.9	+56.6**
				FORMALDEHYDE					
	Conc. (ppm)								
Gastec	2.4	59.8	+40.2**	20.9	+102.9**	20.2	+ 9.5	14.8	+66.7**
	4.5	20.9	+52.3**	17.2	+60.8**	33.1	-12.5	4.7	+55.6**
Drager	2.4	12.1	+126.3**	51.3	+97.1**	—	—	—	—
	4.5	38.4	-10.3	67.9	+484.7**	41.5	-37.4**	57.7	+324.2**

*% Cov = Percent Coefficient of Variation = $\frac{\text{Standard Deviation}}{\text{Mean}} \times 100\%$

% Diff = Percent Difference = $\frac{\text{Measured Conc. - Actual Conc.}}{\text{Actual Conc.}} \times 100\%$

**Values exceed those acceptable for certification of detector tubes: ± 25% at 1 to 5 times the exposure limit (OSHA Std.)

I. CO:

A. Humidity

No bias in the CO readings appears to be attributable to the humidity conditions at which the experiment was performed.

B. Temperature

In low temperature, Brand 1 was read too high. Observer readings for Brand 1 were too low when CO concentrations at twice the OSHA Standard and high temperatures were used.

II. CO_2:

A. Humidity

In high humidity, readings at the OSHA Standard concentration for Brand 2 indicated a greater concentration of CO_2 than was actually present. At 20%

relative humidity (in the temperature analyses) Brand 1 was read too high (but not in excess of 25%).

B. Temperature

No indication was found which would support the theory that extreme temperatures at which the test was performed affect either brand's readings.

III. NO:

A. Humidity

At low humidity, the Brand 1 readings of NO were too low. (There is, however, strong evidence of a general trend for the Brand 1 readings to be too low and the Brand 2 readings to be too high, which may have wrongly led to this conclusion.) From Table IV, although Brand 1 read low, it was not significantly low. Brand 2 gave high readings at high humidity at a concentration of twice the OSHA Standard.

B. Temperature

At high temperatures, the NO readings of Brand 2 were too high.

IV. NO_2:

A. Humidity

At high humidity, Brand 1 readings were too high. This positive bias appears to be greater at concentrations twice the OSHA Standard than at the OSHA Standard. Readings for Brand 2 exhibited a significant positive bias at the low humidity level when twice the OSHA Standard concentration of NO_2 was to be observed.

B. Temperature

Brand 1 was read as too high in low temperatures and too low in high temperatures. Brand 2 was too low at the OSHA Standard concentration at both high and low temperatures.

V. SO_2:

A. Humidity

High readings were exhibited by both brands of tubes in high humidity at all concentrations used. The positive bias in the SO_2 readings appeared to increase with an increase in concentration with the bias being greater for Brand 2 readings than those of Brand 1. Brand 2 readings were too low when observing the OSHA Standard in low humidity. In low humidity, when observing a concentration of twice the OSHA Standard of SO_2, Brand 1 exhibited readings which were too high.

B. Temperature

Brand 2 readings were too low for SO_2 at low temperatures. At high temperatures the Brand 2 tubes were read too high, with the severity of this positive bias appearing to increase with increasing concentrations of SO_2.

VI. H_2S:

A. Humidity

Humidity appears to have no significant effect on the performance of either brand of tubes.

B. Temperature

Readings for Brand 2 at high temperature indicated too low concentration of H_2S.

VII. CH_2O:

A. Humidity

Both tubes read excessively high at all concentrations and humidity levels. The one exception was for Brand 2 at low humidity, with a concentration of twice the OSHA Standard.

B. Temperature

Readings from Brand 1 indicated a higher concentration of CH_2O present than actually existed when in high temperatures. Brand 2 read high at both high and low temperatures (data at the OSHA Standard was lost).

summary

In general, humidity and temperature affect the readings of both brands of gas detector tubes with a severity which is dependent upon the concentration being observed. Of the twelve certified tubes that were tested, eight would have failed the certification testing if the conditions of high and low temperature and humidity which were used in this experiment had been required in the certification program.