VALTRONICS

Application Note A30:
Effect of Relative Humidity upon NDIR Volumetric Gas Measurement

This application note was created to show how relative humidity (RH) effects volumetric gas monitors. The % change column represents an effect on the SPAN (up scale) reading and not on ZERO.

A question that sometimes is asked: If you calibrate one of our gas sensors in fairly dry air of about 35% RH would it read accurately at 95% RH? Since **all** NDIR (non-dispersive infra-red) gas sensors are based on a volumetric measurement, the displacement of gas molecules by water vapor molecules affects the unit's calibration. The following discussion assumes **gas calibration was done at sea level (760 mm Hg), 104°F (40°C), and 35% RH** and determines the effect of a **relative humidity increase to 95% RH**. The quantified effect is that the **gas reading** would be **lowered by 4.43%** (if the sensor was gas calibrated with 2.0% CO_2 by volume at 35% RH, it would read 1.95%CO_2 at 95% RH) as described below:

Saturation vapor pressure over water

Temperature/pressure °C	°F	Sat Vapor pres mmHg
0	32.0	4.6
10	50.0	9.2
20	68.0	17.7
30	86.0	27.0
40	104.0	55.3
50	122.0	86.0
60	140.0	150.0

Saturated water vapor as a fraction of metered volume as a function of absolute pressure and temp.

Temperature/pressure °C	°F	400 mm Hg	500 mm Hg	600 mm Hg	700 mm Hg	**760** mm Hg	800 mm Hg
0	32.0						
10	50.0	0.0230					
20	68.0	0.0440	0.0355	0.0295	0.0255	0.0233	0.0220
30	86.0	0.0800	0.0670	0.0531	0.0455	0.0420	0.0400
40	104.0	0.1900	0.1230	0.0925	0.0800	**0.0738**	0.0700
50	122.0	0.2680	0.1920	0.1560	0.1340	0.1230	0.1170
60	140.0	0.3750	0.3000	0.2500	0.2140	0.1980	0.1870
70	158.0	0.5870	0.4700	0.3900	0.3350	0.3200	0.2850
80	176.0	0.8900	0.7150	0.5950	0.5200	0.4680	0.4450
90	194.0			0.8800	0.7280	0.6950	0.6300
100	212.0					1.0000	0.9550

The term ***relative humidity*** is defined as the ratio of the actual vapor pressure to the saturated vapor pressure at the temperature of the air. Thus, if RH is the relative humidity, p the actual vapor pressure, and P the saturated vapor pressure at the temperature of the air, then RH = p/P and is expressed in percentages. For example, suppose that the actual vapor pressure is 19.36 mm of mercury when the temperature of the air is 40°C. Since the saturated vapor pressure at this temperature is 55.32 mm of mercury, the relative humidity is RH = 19.36/55.32 = 35% There are 51.12 grams of water vapor in a cubic meter of saturated air at 40°C (104°F) which will take up about 7.38% of its volume (from the table). Since the air is only 35% saturated, the air will be displaced by 0.35 x 0.0738 = 0.02583 = 2.58% water vapor. The difference between 35% RH and 95% RH is 0.95 x 0.0738 = 0.0701 = 7.01% water vapor @95% RH minus the 2.58% water vapor @ 35% RH which is 4.43% water vapor difference. This means that there are 4.43% less molecules by volume of other compounds in the air including gases like CO_2 or CH_4 when you go from 35% RH to 95% RH.

Take the case of a given mass (number of molecules) of CO_2, like our 1000 ppm (0.1%) calibration gas (99.9% N_2) occupying a volume such as our sample cell. The number of molecules that will occupy the space between the infrared source (emitter) and the infrared bandpass filter / detector depends on how far apart the molecules are. The average distance between molecules depends on pressure and temperature since the volume is constant. The number of molecules of CO_2 in the optical path will determine how much infrared energy at the specific CO_2 wavelength is absorbed. See page 2 for a generalized chart that shows the effect of temperature on the number of molecules in the gas cell for all gases.

Amedeo Avogadro (1776-1856), Italian chemist and physicist, determined in 1811 that all gases occupying equal volumes at the same temperature and pressure contain equal numbers of molecules. **Avogadro's number** is $\underline{6.023 \times 10^{23}}$ molecules per gram molecular weight. A molar volume, 22.4 liters at 0°C and 76 cm mercury (Hg) pressure, is the volume occupied by a gram molecular weight of gas (any gas). Our Model 2004AD and 2004AS gas cell has a volume of 3.61 mL. It will contain 9.71×10^{19} molecules at 0°C and 76 cm Hg. Of those only 5% will be methane molecules when 5% CH_4 is in the cell. This means that there will be 4.855×10^{18} molecules of CH_4 in the cell at 0°C and 76 cm Hg. The chart below shows how the number of molecules and therefore the percent absorption (scale response) changes as a function of ambient and gas cell temperature. The percentage change can be applied to all gases.

Effect of temperature on the number of molecules in the gas cell for all gases.
Gas calibration is assumed at 0°C or 273.2°K (absolute).

°C	°F	% change
-55	-67.0	**20.13%**
-54	-65.2	**19.76%**
-53	-63.4	**19.40%**
-52	-61.6	**19.03%**
-51	-59.8	**18.66%**
-50	-58.0	**18.30%**
-49	-56.2	**17.93%**
-48	-54.4	**17.57%**
-47	-52.6	**17.20%**
-46	-50.8	**16.83%**
-45	-49.0	**16.47%**
-44	-47.2	**16.10%**
-43	-45.4	**15.74%**
-42	-43.6	**15.37%**
-41	-41.8	**15.00%**
-40	-40.0	**14.64%**
-39	-38.2	**14.27%**
-38	-36.4	**13.91%**
-37	-34.6	**13.54%**
-36	-32.8	**13.17%**
-35	-31.0	**12.81%**
-34	-29.2	**12.44%**
-33	-27.4	**12.08%**
-32	-25.6	**11.71%**
-31	-23.8	**11.34%**
-30	-22.0	**10.98%**
-29	-20.2	**10.61%**
-28	-18.4	**10.25%**
-27	-16.6	**9.88%**
-26	-14.8	**9.51%**
-25	-13.0	**9.15%**
-24	-11.2	**8.78%**
-23	-9.4	**8.42%**
-22	-7.6	**8.05%**
-21	-5.8	**7.68%**
-20	-4.0	**7.32%**
-19	-2.2	**6.95%**
-18	-0.4	**6.59%**
-17	1.4	**6.22%**
-16	3.2	**5.85%**
-15	5.0	**5.49%**
-14	6.8	**5.12%**
-13	8.6	**4.76%**
-12	10.4	**4.39%**
-11	12.2	**4.02%**
-10	14.0	**3.66%**
-9	15.8	**3.29%**
-8	17.6	**2.93%**
-7	19.4	**2.56%**
-6	21.2	**2.19%**
-5	23.0	**1.83%**
-4	24.8	**1.46%**
-3	26.6	**1.10%**
-2	28.4	**0.73%**
-1	30.2	**0.36%**
0	**32.0**	**0.00%**
1	33.8	**-0.37%**
2	35.6	**-0.73%**
3	37.4	**-1.10%**
4	39.2	**-1.47%**
5	41.0	**-1.83%**
6	42.8	**-2.20%**
7	44.6	**-2.56%**
8	46.4	**-2.93%**
9	48.2	**-3.30%**
10	50.0	**-3.66%**
11	51.8	**-4.03%**
12	53.6	**-4.39%**
13	55.4	**-4.76%**
14	57.2	**-5.13%**
15	59.0	**-5.49%**
16	60.8	**-5.86%**
17	62.6	**-6.22%**
18	64.4	**-6.59%**
19	66.2	**-6.96%**
20	68.0	**-7.32%**
21	69.8	**-7.69%**
22	71.6	**-8.05%**
23	73.4	**-8.42%**
24	75.2	**-8.79%**
25	77.0	**-9.15%**
26	78.8	**-9.52%**
27	80.6	**-9.88%**
28	82.4	**-10.25%**
29	84.2	**-10.62%**
30	86.0	**-10.98%**
31	87.8	**-11.35%**
32	89.6	**-11.71%**
33	91.4	**-12.08%**
34	93.2	**-12.45%**
35	95.0	**-12.81%**
36	96.8	**-13.18%**
37	98.6	**-13.54%**
38	100.4	**-13.91%**
39	102.2	**-14.28%**
40	104.0	**-14.64%**
41	105.8	**-15.01%**
42	107.6	**-15.37%**
43	109.4	**-15.74%**
44	111.2	**-16.11%**
45	113.0	**-16.47%**
46	114.8	**-16.84%**
47	116.6	**-17.20%**
48	118.4	**-17.57%**
49	120.2	**-17.94%**
50	122.0	**-18.30%**
51	123.8	**-18.67%**
52	125.6	**-19.03%**
53	127.4	**-19.40%**
54	129.2	**-19.77%**
55	131.0	**-20.13%**
56	132.8	**-20.50%**
57	134.6	**-20.86%**
58	136.4	**-21.23%**
59	138.2	**-21.60%**
60	140.0	**-21.96%**
61	141.8	**-22.33%**
62	143.6	**-22.69%**
63	145.4	**-23.06%**
64	147.2	**-23.43%**
65	149.0	**-23.79%**
66	150.8	**-24.16%**
67	152.6	**-24.52%**
68	154.4	**-24.89%**
69	156.2	**-25.26%**
70	158.0	**-25.62%**

5% Methane (CH_4)

Temperature in			# of CH4	% change
°K	***°C***	***°F***	molecules	molecules
210	-63.2	-81.76	5.98E+18	23.13%
215	-58.2	-72.76	5.89E+18	21.30%
220	-53.2	-63.76	5.80E+18	19.47%
225	-48.2	-54.76	5.71E+18	17.64%
230	-43.2	-45.76	5.62E+18	15.81%
235	-38.2	-36.76	5.53E+18	13.98%
240	-33.2	-27.76	5.44E+18	12.15%
245	-28.2	-18.76	5.36E+18	10.32%
250	-23.2	-9.76	5.27E+18	8.49%
255	-18.2	-0.76	5.18E+18	6.66%
260	-13.2	8.24	5.09E+18	4.83%
265	-8.2	17.24	5.00E+18	3.00%
270	-3.2	26.24	4.91E+18	1.17%
273.2	**0.0**	**32.00**	4.86E+18	**0.00%**
275	1.8	35.24	4.82E+18	-0.66%
280	6.8	44.24	4.73E+18	-2.49%
285	11.8	53.24	4.65E+18	-4.32%
290	16.8	62.24	4.56E+18	-6.15%
295	21.8	71.24	4.47E+18	-7.98%
300	26.8	80.24	4.38E+18	-9.81%
305	31.8	89.24	4.29E+18	-11.64%
310	36.8	98.24	4.20E+18	-13.47%
315	41.8	107.24	4.11E+18	-15.30%
320	46.8	116.24	4.02E+18	-17.13%
325	51.8	125.24	3.93E+18	-18.96%
330	56.8	134.24	3.85E+18	-20.79%
335	61.8	143.24	3.76E+18	-22.62%
340	66.8	152.24	3.67E+18	-24.45%
345	71.8	161.24	3.58E+18	-26.28%