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Measurement and Analysis of Adsistor and Figaro Gas Sensors Used for Underground Storage Tank Leak Detection

by

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ABSTRACT

Gas sensor properties were measured with the purpose of comparing two sensor technologies used for underground storage tank leak detection. Figaro™ gas sensors and the Adsistor™ gas sensor were tested in simulated underground storage tank environments using the Carnegie Mellon Research Institute (CMRI) automated gas testing facilities. This automated system monitored the sensors' responses while dynamically exposing them to various mixtures of methane, butane and xylene. The sensors were also tested to determine the effects of humidity on their responses. Sensor responses were characterized by sensitivity, selectivity, and speed of response and recovery to selected test concentrations of methane, butane, and xylene. The test results are presented as a list of sensor specifications to allow the potential end user a direct comparison of these two different types of sensors.

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1.0 INTRODUCTION

Over two million underground storage tanks (UST) are currently being regulated by the U. S. Environmental Protection Agency (EPA). By 1993, the vast majority of these tanks are required to be equipped with leak detection monitors to alert tank owners of any problems. Vapor monitoring equipment, housed in monitoring wells surrounding the UST, is a common choice for monitoring the environment for gasoline or product spills from a leaky tank.

The concept behind vapor monitoring is that a small liquid leak will generate a large increase in product vapor concentration. By proper placement of the monitoring wells, the product vapor will readily migrate to these wells. There, the vapor sensors will detect the increased contaminant vapor concentrations and initiate an alarm.

This study was initiated by the EPA Office of Underground Storage Tanks to help the regulators of UST vapor-phase product leak detectors to better understand the capabilities and limitations of commercial vapor sensors used in continuous vapor phase product leak detectors. The study was limited to characterizing two types of commercial vapor sensors: The Figaro Gas [1] Sensor and the Adsistor Vapor [2] Sensor. Appendix A contains product literature for these commercially available sensor types.

Four types of Figaro gas sensors, model numbers 812, 813, 822, 823, and the Adsistor gas sensor were tested in simulated UST environments using the Carnegie Mellon Research Institute (CMRI) automated gas testing facilities. The characterization of these sensors resulted in a set of specifications that allows comparison between the different sensor types. The Figaro sensors are metal oxide semiconductor devices that operate at elevated temperature [1]. The Adsistor sensor operates at ambient temperature, using the principle of gas adsorption [2] in a polymeric material.

The selection of test gases was based upon a study performed by Geoscience Consultants, Ltd., in 1988 [3]. This study detailed the hydrocarbon vapor concentration at 27 gasoline service stations from three diverse geographic regions of the United States.

Their findings indicated that:

- all the surveyed locations had some evidence of underground methane and gasoline vapor products.
- methane existed in high concentrations at many locations.
- tracking butane concentrations would be useful in detecting recent gasoline leaks or spills.
- m-xylene was a large component of gasoline product s(Table 1.1).

Table 1.1: Gasoline Components

Compound	Percent Weight
2-Methylbutane	8.72
m-Xylene	5.66
2,2,4-Trimethylpentane	5.22
Toluene	4.73
2-Methylpentane	3.93
n-Butane	3.83
1,2,4-Trimethylbenzene	3.26
n-Pentane	3.11
2,3,4-Trimethylpentane	2.99
2,3,3-Trimethylpentane	2.85
3-Metylpentane	2.36
o-Xylene	2.27
Ethylbenzene	2.00
Benzene	1.94
p-Xylene	1.72
2,3-Dimethylbutane	1.66
n-Hexane	1.58
1-Methyl, 3-Ethylbenzene	1.54
1-Methyl, 4-Ethylbenzene	1.54
3-Methylhexane	1.30

Based on this study, methane was chosen as a potential interference that may cause false alarms for UST monitors. Also iso-butane and m-xylene were chosen as tag compounds because they represent major chemical constituents in gasoline.

The sensors were tested to determine their sensitivity and cross sensitivities to methane, butane, xylene, and humidity. These tests would help the UST leak detector manufacturers to better understand how to recommend the use of these sensors. For example, 1) If a sensor responds to methane, but the instrument's user is unaware of this sensitivity, then this instrument placed in the field could produce false alarms due to methane interference. 2) The humidity level underground at UST sites is considered to be near saturation [4]. Therefore, if a monitor is calibrated with a dry gas, and the sensor is placed in the damp underground environment, this also could lead to false alarms, or worse, no alarm will be initiated when a real leak is occurring.

Response time is not a critical sensor parameter for this application as leaks in USTs generally occur slowly, and site monitoring is done on time scales of days and not minutes. However, recovery time can be important in situations where an accidental spill occurs. In this case, if a sensor takes too long to recover from the spill, the detection of a true leak could be masked.

The reproducibility of sensor properties is also essential in maintaining instrument quality control. For example, when a sensor fails and is replaced, if the replacement sensor behaves differently, errors in monitoring a site are very likely. By knowing the limitations of the reproducibility of various sensor types, steps can be taken to properly check the perfomance of replacement sensors to assure the monitoring equipments' performance is known.

Sensor responses were characterized by sensitivity, selectivity, and speed of response and recovery to selected test concentrations of methane, butane, and xylene. The test results are presented as tables of sensor specifications to show the potential end user the advantages and disadvantages of using various sensor types for monitoring underground storage tanks.

2.0 EXPERIMENTAL

The data presented were collected using the CMRI automated gas sensor characterization facility. The facility has been designed to study the behavior of gas sensors and characterize their response in terms of sensitivity, selectivity, speed of response and recovery, and stability. A computer-controlled gas delivery and data acquisition system (GDS), Figure 2.1, creates the test atmosphere in the sensor test chamber and records the corresponding sensor responses. The GDS controls and sets proper levels of oxygen, nitrogen, and water vapor to create a clean baseline environment through a network of mass flow dilution modules. This clean air can then be contaminated with up to five different vapor compounds. For this study, the facility was modified to independently set concentrations for methane, (CH_4), butane (C_4H_8), and m-xylene (C_8H_{10}). The GDS was set to maintain a constant flow rate of 1 liter/minute.

A second gas system, delivering clean humidified air, was used to maintain the sensor atmosphere when the sensor chambers were not connected to the GDS.

An on-line gas chromatograph was used to verify the concentration delivered to the test chamber both during and between tests.

Three test chambers were built to house the sensors. One chamber was built to test nine Adsistor Sensors and two chambers to house 12 Figaro Sensors, 6 of each type. All the materials used in the construction of the chambers were chosen to minimize undesirable out-gassing that might contaminate the test atmosphere. The chambers also had the capabilities to power the sensors and monitor their responses in accordance with manufacturer's recommendations. The volume of each test chamber was 1.2 liters.

The Adsistor chamber consisted of an aluminum plate and a glass-epoxy based printed circuit board, mounted on standoffs. Standard clamp pins were inserted into the circuit board for connecting to the data acquisition unit, and mounting the Adsistors. Adsistors were soldered onto clamp pins and their resistance measured with the GDS multi-meter. Precautions were taken to ensure that the solder flux did not interfere with the Adsistors, following the manufacturer's recommendations. A glass lid was used to complete the chamber construction. Gas flowed into the chamber through a feed-through in the bottom of the aluminum plate.

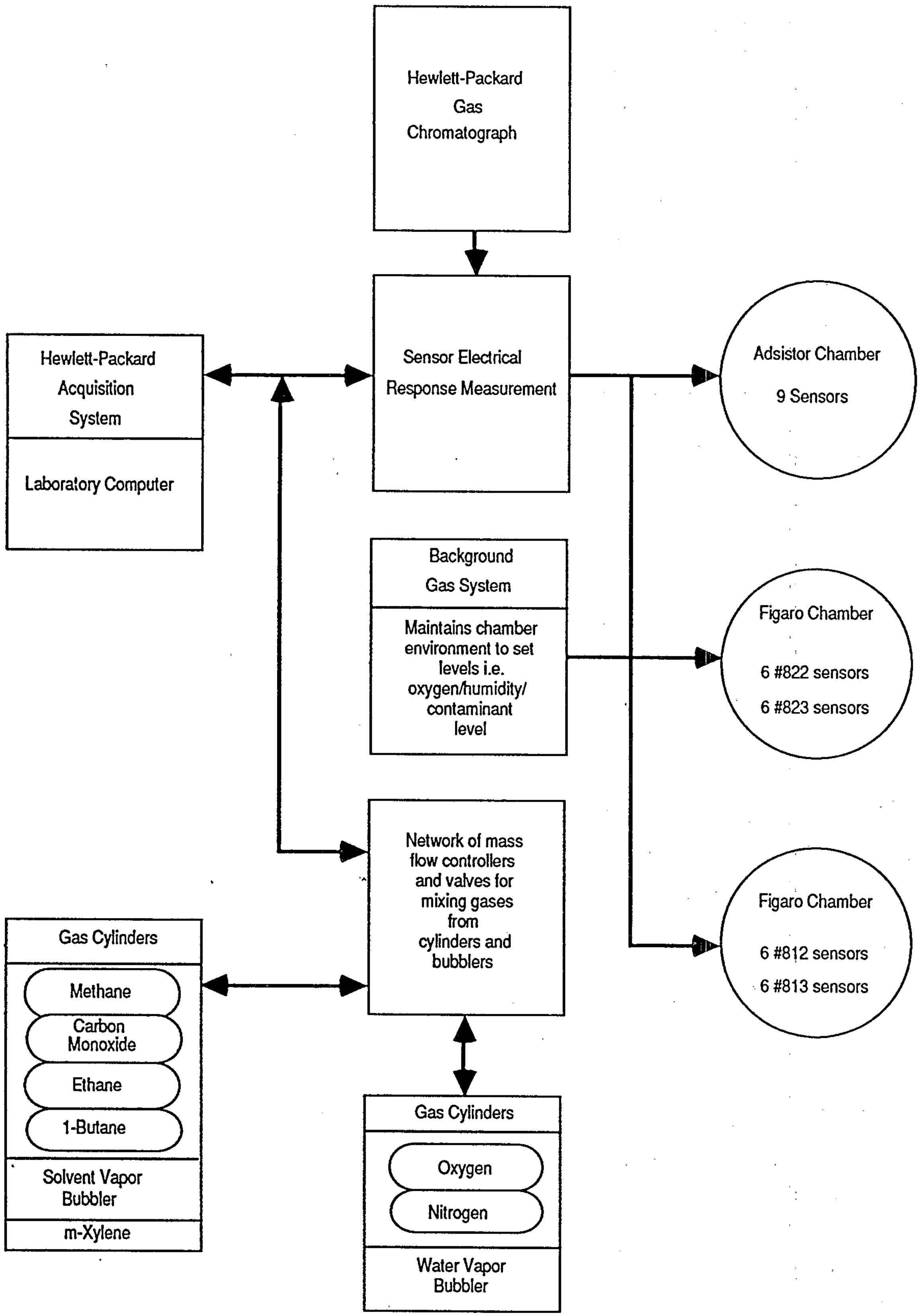


Figure 2.1: CMRI Gas Sensor Characterization Facility

The two Figaro chambers contained six 822 and six 823 sensors and six 812 and six 813 sensors, respectively. Both consisted of an aluminum plate mounted with 12 Figaro sockets. These 12 sockets were mounted to form a 5.75 inch diameter* circle. Thermocouples were also installed to monitor chamber temperature. As with the Adsistor chamber, a feed-through was tapped into the center of the aluminum plate for the gases to enter into the chamber, and a glass lid was used to complete the chamber housing.

The sensors were powered and calibrated according to Figaro manufacturer instructions. Sensor heaters were all powered using a 5-volt power supply. The sensor bias voltage was maintained at 10 volts. Precision load resistors (R_l=3920 ohm ±1%) were installed in series with the sensor leads. Sensor signals were measured by reading the voltage across the load resistor according to Figaro instructions. All wiring was done on the outside of the chamber to prevent interference with sensor responses.

Test chamber temperatures were monitored during testing. The Adsistor test chamber temperature operated at room temperature, 22°C ± 1°C. The Figaro test chambers ran hotter, at 33°C ± 1°C, due to the local heating induced by the Figaro sensors' operating power requirements.

3.0 SENSOR CONSTRUCTION AND MODEL EQUATIONS

To simplify direct comparison of these sensors, mathematical models were used to convert sensor resistance (ohms) into gas concentration (ppm). The model chosen for the Adsistor is the one suggested by the manufacturer [2]. The model selected for the Figaro sensors is commonly used according to the literature [5].

3.1 The Adsistor Sensor

The Adsistor sensor looks like a small resistor, Figure 3.1. It is specially coated to make it sensitive to gas vapors. The Adsistor sensor requires no power to operate and is monitored by measuring its resistance like a common resistor.

The base of the coating is a non-conductive, resilient polymer which holds in place conductive particles. The phenomena of adsorption is the basis for the sensor's sensitivity. In an ambient air environment, the particles, each independently anchored to the polymer surface, are in contact with each other forming an electrical path. When a contaminant vapor comes in contact with the particle surface, a mono-layer of contaminant molecules is adsorbed onto the particle surfaces. Van der Waal's adsorption forces (adhesion of gas molecules to the surface of a solid) cause separation between each of the particles increasing the electrical path's resistance. The electrical resistance measured across an Adsistor is determined by the amount and type of gas molecule adsorbed to its surface [6].

Adsistor sensor data was collected by measuring the sensor's electrical resistance. The resistance is related to concentration for most gas vapor concentrations by equation 1.

Eqn. 1 $$R = R_b 10^{c/k}$$

where
R = Measured resistance
R_b = Resistance in clean air,
k = Gas constant at ambient temperature
c = Gas concentration (ppm)

The Adsistor sensor resistance versus concentration is reported to be a straight line when plotted on a semi-log graph [2].

The model was tested for xylene by exposing the sensors to a xylene concentration ramp of 100 ppm to 1000 ppm in 100 ppm steps. The resistance versus xylene concentration curve is plotted in Figure 3.2. This curve is not a straight line. This may indicate that the sensor is not sufficiently sensitive to the lower xylene concentration range.

Because the sensors did not respond to the lower test concentration, a two point fit between the 100 and 1000 ppm xylene was used to determine R_b and k in equation 1. Solving equation 1 for c yields equation 2 which is used to translate the measured Adsistor resistance into a measured gas concentration.

Eqn. 2 $$c = k \log10(R/R_b)$$

Figure 3.1: Adsistor Sensor Construction

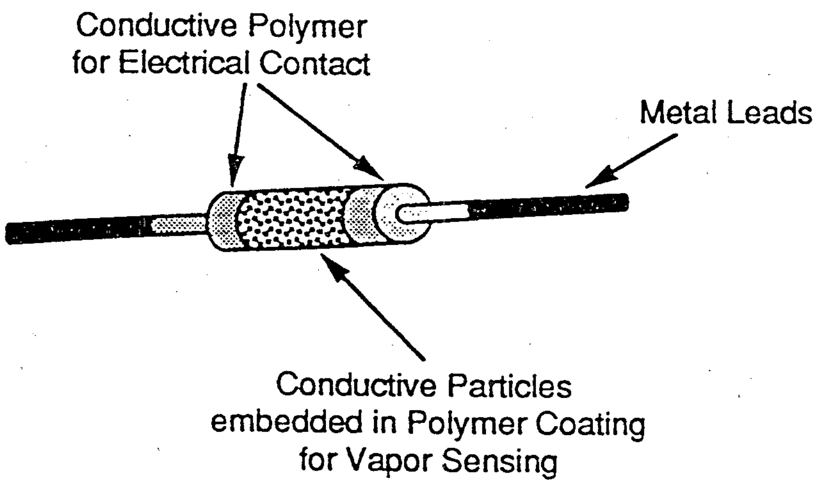
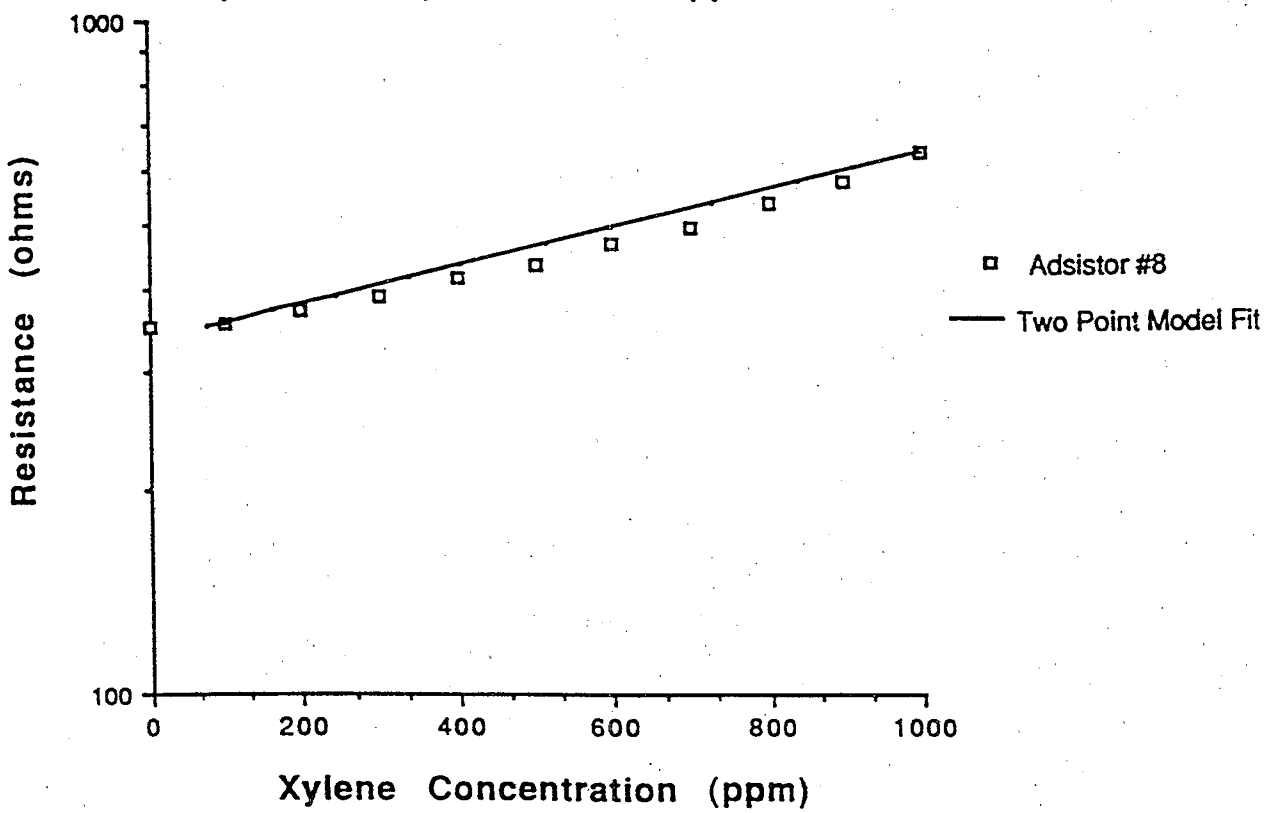


Figure 3.2: Adsistor Measured and Fitted Response to Xylene at 15 K ppm H2O



3.2 The Figaro Sensor

The construction of a Figaro sensor is shown in Figure 3.3a. The sensor is primarily composed of tin oxide sintered on a small ceramic tube. Noble metal wires are used to provide electrical contact between the sintered tin oxide and the electronics used to measure its resistance. The noble metal wires also provide mechanical support. Through the center of the ceramic tube, a coiled wire is positioned to serve as the sensor heater.

The Figaro sensors require a small amount of power to operate the sensor element at elevated temperatures between 200°C to 400°C. By varying the composition of the sensor element and/or the operating temperature, Figaro has been able to alter the sensor's response to various combustible gases.

For this project, the sensors were powered and measured according to the manufacturer's instructions. Sensor heaters were all powered using a 5-volt power supply. The sensor bias voltage was maintained at 10 volts. Precision load resistors (R_l=3920 ohm ±1%) were installed in series with the sensor leads (Figure 3.3b). Sensor signals were measured by reading the voltage across the load resistor.

The Figaro sensors respond to changes in the partial pressure of oxygen. At a set oxygen level, oxygen is adsorbed on the surface of the gas sensing Metal Oxide Semiconductor (MOS) sensor. This adsorption of oxygen on the semiconductor is strong enough to promote electron transport from the semiconductor to the adsorbed oxygen. In the presence of a fixed oxygen environment such as ambient air, an equilibrium state is achieved and the sensor electrical resistance (baseline) is established. If the environment is then contaminated with a combustible gas, a surface catalyzed combustion reaction occurs. This reaction causes the surface adsorbed and negatively charged oxygen to be reduced, returning the shared electron to the semiconductor, and decreasing the semiconductor's electrical resistance. The relationship between the amount of change in resistance to the concentration of a combustible gas is non-linear and can be expressed by a power law equation.

Figaro sensor data was collected and converted to sensor resistance using equation 3.

Eqn. 3 $$R = R_l\,(V_B - V_R)/V_R$$

where
R = Resistance (ohms)
R_l = Load resistor (3920 ohms)
V_B = Voltage bias (10 volts)
V_R = (10-V_B) = Sensor voltage

The resistance concentration curve was observed to be approximately linear on a log - log plot. Therefore, a power law model was adopted for these sensors as seen in equation 4.

Eqn. 4 (a) $\log(R) - \log(R_o) = \beta \log(c)$

(b) $R/R_o = c^{\beta}$

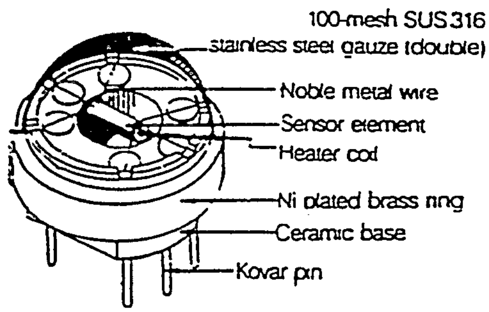
where
R = Sensor resistance
c = Gas concentration (ppm)
β = Power law slope
R_o = Sensor resistance when $c=1$

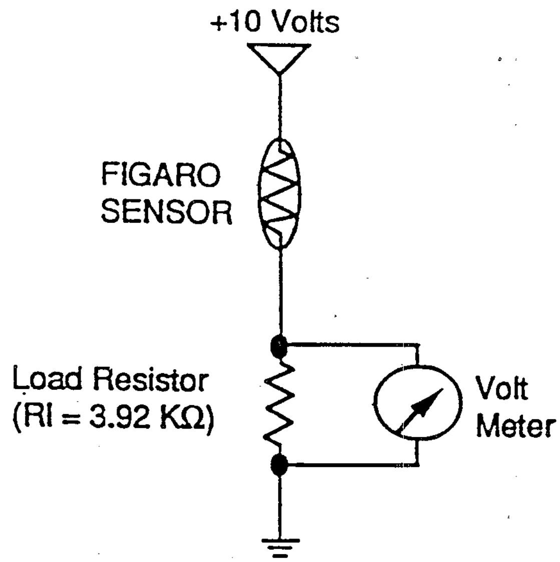
The two parameters R_o and β are determined by considering measurements taken at $c = 100$, and $c = 1000$ ppm for the gas in question. Once the parameters are determined, the sensor resistance is translated into concentration by inverting equation 4 and shown in equation 5.

Eqn. 5
$$c = \frac{R}{R_o}^{\frac{1}{\beta}}$$

A plot showing how the model fits the sensor response for a Figaro 823 is shown in Figure 3.4.

Figure 3.3: Figaro Sensor

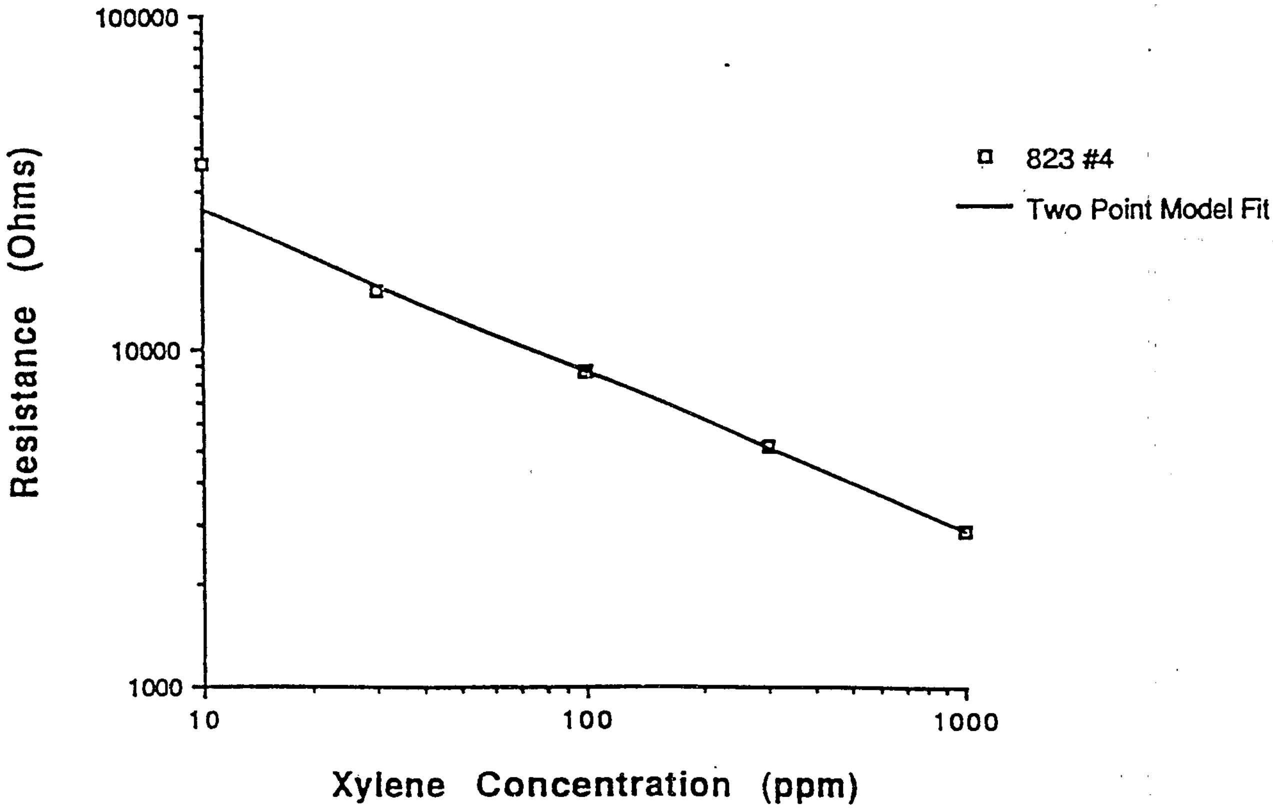




a) **Sensor Construction**
reprinted from Figaro Literature

b) **Measurement Circuit**

Figure 3.4: Figaro 823 Measured and Fitted Response to Xylene at 15 K ppm H2O



4.0 TEST DESCRIPTIONS

Four specific kinds of tests were performed to characterize sensor response. Each of the following tests were designed to measure one or more specific sensor properties:

4.1 Gas Concentration Ramp Test

The Gas Concentration Ramp Test measures a sensor's sensitivity and selectivity to individual test gases. The test exposes the sensors to individual test gases at five different concentrations. The test concentration ranges were 0, 50, 150, 500, 1500, 5000 ppm for methane and butane and 0, 10, 30, 100, 300, 1000 ppm for xylene. Each concentration was held for thirty minutes before proceeding to the next level. The sensors were exposed to clean air for two hours between each ramp.

Ramp tests were performed at two humidity levels. The first set was conducted at 15,000 ppm of water vapor. This level was chosen to represent the humidity present at underground storage sites (97% Relative Humidity at 55°F). The second set was done in dry air (less than 50 ppm water vapor) to simulate sensor response when exposed to dry calibration gases.

4.2 Target Gas Excursion Test

The Target Gas Excursion Test determines how the presence of multiple test gases affect a sensor's sensitivity and selectivity. The test creates a background test atmosphere composed of 500 ppm methane, 500 ppm butane, and 100 ppm xylene in air containing 15,000 ppm of water vapor. During the test, each gas is then individually increased to 10 times its background level for thirty minutes.

4.3 Water Vapor Excursion Test

The Water Vapor Excursion Test measures sensor response to the changes in humidity in the presence of multiple test gases. The tests create the same background test atmosphere used in the target gas excursion test. The water vapor concentration is then changed in thirty minute steps from 15,000 ppm, to 5000 ppm, to 1667 ppm, to 0 ppm water vapor, and then set back to 15,000 ppm.

4.4 Response and Recovery Time Test

The Response and Recovery Time Test determines how fast a sensor responds to changes in gas concentration. The tests were performed in air humidified to 15,000 ppm water vapor. The sensors were measured at one minute intervals during the test. The xylene concentration was changed in thirty minute steps from 0 ppm, to 1000 ppm, to 100 ppm, to 1000 ppm and back to 0 ppm.

The response time is defined as the interval from when the new gas concentration is first introduced into the chamber until the sensor reaches 95% of its reading at thirty minutes. The recovery time is defined as the time from when the new gas concentration is first introduced into the chamber until the sensor reaches 95% of the total change in the sensor reading.

5.0 RESULTS and DISCUSSION

The set of tests, described in section 4.0, bracket a range of conditions that vapor sensors are likely to be exposed to at UST sites. Tables 5.1 - 5.7 summarize the performance results of the Adsistor and Figaro sensors for the test conducted.

The measured sensor responses were converted from resistance to ppm units using the model equations described in sections 3.1 and 3.2. Each sensor was fitted individually with a two point calibration. Tables 5.1 - 5.5 report the results of individual test gases with regard to the sensor:

- model parameters
- sensitivity
- humidity affects on sensitivity/vapor response
- cross sensitivity, also called selectivity
- response time
- recovery time

Tables 5.6 and 5.7 list the results of multiple test gases with respect to the affects of humidity and cross sensitivities on sensor response.

The tabulated data are the average of nine Adsistor sensors, and six of each Figaro sensor type. The data are reported as the average measured sensor response along with the standard deviation and percent standard deviation.

The response for all the individual sensors tested is tabulated in Appendix B.

Examples in sections 5.1 - 5.5. focus on the Adsistor sensor and the Figaro 823 sensor. The discussion of tabulated data and the presentation of graphical examples show how the data were analyzed and are related to sensor properties.

The Figaro 823 was chosen for illustrating the behavior of Figaro sensors for several reasons: first, the test results document that the Figaro 812, 822, and 823 sensors all have comparable responses, considering the statistical spread in their respective responses. Second, the Figaro 812 sensor has been discontinued, being replaced by the 822 model. The 822 and 823 sensors are described by Figaro as being the same sensor but packaged differently. Finally, the Figaro 813 sensors is very sensitive to methane and is of limited use for monitoring UST product leaks.

Table 5.1: Adsistor Sensor Specifications

Xylene Model Parameters			
@ 15 K ppm H2O	Average	Std. Dev.	% Dev.
K	2987.72	308.26	10.3%
Rb	3.5E+02	3.5E+01	10.0%
Xylene Readings (ppm) @ 15 K ppm H2O Calibrated at 100 and 1000 ppm Xylene			
Xylene Delivered (ppm)	Average	Std. Dev.	% Dev.
10	61.5	2.8	4.6%
30	67.9	2.3	3.4%
100	100.0	0.0	0.0%
300	233.3	3.7	1.6%
1000	1000.0	0.0	0.0%
Xylene Readings (ppm) @ 0 K ppm H2O			
Xylene Delivered (ppm)	Average	Std. Dev.	% Dev.
10	118.9	13.1	11.1%
30	126.4	12.5	9.9%
100	139.0	12.1	8.7%
300	251.3	10.7	4.3%
1000	997.6	9.7	1.0%
Cross Sensitivity (ppm Xylene)			
@ 15 K ppm H2O	Average	Std. Dev.	% Dev.
5000 ppm Methane	62.9	4.0	6.3%
5000 ppm Butane	61.8	3.2	5.2%
95% Response Time (Minutes)			
@ 15 K ppm H2O	Average	Std. Dev.	% Dev.
0 to 1000 ppm	7.29	1.5	18.6%
100 to 1000 ppm	7.86	1.8	20.5%
95% Recovery Time (Minutes)			
@ 15 K ppm H2O	Average	Std. Dev.	% Dev.
1000 to 100 ppm	> 30	0.0	0.0%
1000 to 0 ppm	> 30	0.0	0.0%

Table 5.2: Figaro 823 Sensor Specifications

Xylene Model Parameters			
@ 15 K ppm H2O	Average	Std. Dev.	% Dev.
B	0.56	0.12	21.4%
Ro	9.1E+04	3.6E+04	39.6%

Xylene Readings (ppm) @ 15 K ppm H2O Calibrated at 100 and 1000 ppm Xylene			
Xylene Delivered (ppm)	Average	Std. Dev.	% Dev.
10	10.7	5.8	53.8%
30	43.5	10.0	23.0%
100	100.0	0.0	0.0%
300	239.9	36.1	15.0%
1000	1000.0	0.0	0.0%

Xylene Readings (ppm) @ 0 K ppm H2O			
Xylene Delivered (ppm)	Average	Std. Dev.	% Dev.
10	0.2	0.3	141.3%
30	1.4	1.4	100.0%
100	5.9	4.5	75.0%
300	38.8	21.5	55.4%
1000	437.8	136.7	31.2%

Cross Sensitivity (ppm Xylene)			
@ 15 K ppm H2O	Average	Std. Dev.	% Dev.
5000 ppm Methane	23.5	8.6	36.6%
5000 ppm Butane	793.4	792.9	99.9%

95% Response Time (Minutes)			
@ 15 K ppm H2O	Average	Std. Dev.	% Dev.
0 to 1000 ppm	15.30	6.7	42.3%
100 to 1000 ppm	10.18	7.4	68.7%

95% Recovery Time (Minutes)			
@ 15 K ppm H2O	Average	Std. Dev.	% Dev.
1000 to 100 ppm	3.33	1.0	31.0%
1000 to 0 ppm	4.08	0.9	23.1%

Table 5.3: Figaro 822 Sensor Specifications

Xylene Model Parameters			
@ 15 K ppm H2O	Average	Std. Dev.	% Dev.
B	0.74	0.28	37.2%
Ro	5.1E+05	6.4E+05	124.9%
Xylene Readings (ppm) @ 15 K ppm H2O Calibrated at 100 and 1000 ppm Xylene			
Xylene Delivered (ppm)	Average	Std. Dev.	% Dev.
10	15.5	9.2	59.3%
30	46.9	10.2	21.7%
100	100.0	0.0	0.0%
300	230.0	35.4	15.4%
1000	1000.0	0.0	0.0%
Xylene Readings (ppm) @ 0 K ppm H2O			
Xylene Delivered (ppm)	Average	Std. Dev.	% Dev.
10	1.4	1.9	135.3%
30	4.6	5.3	115.0%
100	13.2	12.8	96.9%
300	55.6	38.3	68.9%
1000	502.0	184.0	36.7%
Cross Sensitivity (ppm Xylene)			
@ 15 K ppm H2O	Average	Std. Dev.	% Dev.
5000 ppm Methane	42.2	16.1	38.2%
5000 ppm Butane	802.2	688.2	85.8%
95% Response Time (Minutes)			
@ 15 K ppm H2O	Average	Std. Dev.	% Dev.
0 to 1000 ppm	16.80	4.7	27.3%
100 to 1000 ppm	10.00	4.6	43.2%
95% Recovery Time (Minutes)			
@ 15 K ppm H2O	Average	Std. Dev.	% Dev.
1000 to 100 ppm	4.70	2.0	43.2%
1000 to 0 ppm	5.39	4.0	62.4%

Table 5.4: Figaro 812 Sensor Specifications

Xylene Model Parameters			
@ 15 K ppm H2O	Average	Std. Dev.	% Dev.
B	0.91	0.14	15.3%
Ro	2.6E+05	1.6E+05	62.6%
Xylene Readings (ppm) @ 15 K ppm H2O Calibrated at 100 and 1000 ppm Xylene			
Xylene Delivered (ppm)	Average	Std. Dev.	% Dev.
10	15.7	4.4	28.2%
30	42.3	6.2	14.6%
100	100.0	0.0	0.0%
300	351.3	103.0	29.3%
1000	1000.0	0.0	0.0%
Xylene Readings (ppm) @ 0 K ppm H2O			
Xylene Delivered (ppm)	Average	Std. Dev.	% Dev.
10	2.2	1.0	46.3%
30	8.7	2.7	30.6%
100	28.4	4.5	16.0%
300	126.8	25.2	19.8%
1000	430.3	111.3	25.9%
Cross Sensitivity (ppm Xylene)			
@ 15 K ppm H2O	Average	Std. Dev.	% Dev.
5000 ppm Methane	30.1	14.6	48.4%
5000 ppm Butane	207.1	75.6	36.5%
95% Response Time (Minutes)			
@ 15 K ppm H2O	Average	Std. Dev.	% Dev.
0 to 1000 ppm	10.18	4.8	44.4%
100 to 1000 ppm	6.51	4.1	55.3%
95% Recovery Time (Minutes)			
@ 15 K ppm H2O	Average	Std. Dev.	% Dev.
1000 to 100 ppm	13.20	7.3	53.6%
1000 to 0 ppm	12.45	5.4	41.6%

Table 5.5: Figaro 813 Sensor Specifications

Methane Model Parameters			
@ 15 K ppm H2O	Average	Std. Dev.	% Dev.
B	0.47	0.03	6.7%
Ro	1.7E+05	2.1E+04	12.3%
Methane Readings (ppm) @ 15 K ppm H2O Calibrated at 500 and 5000 ppm Methane			
Methane Delivered (ppm)	Average	Std. Dev.	% Dev.
50	121.8	18.2	14.9%
150	208.3	20.7	10.0%
500	500.0	0.0	0.0%
1500	1330.4	42.8	3.2%
5000	5000.0	0.0	0.0%
Methane Readings (ppm) @ 0 K ppm H2O			
Methane Delivered (ppm)	Average	Std. Dev.	% Dev.
50	16.6	2.8	16.9%
150	47.1	10.3	21.8%
500	199.6	47.6	23.9%
1500	731.2	112.3	15.4%
5000	3657.5	319.1	8.7%
Cross Sensitivity (ppm Methane)			
@ 15 K ppm H2O	Average	Std. Dev.	% Dev.
5000 ppm Butane	4228.1	1264.9	29.9%
1000 ppm Xylene	363.0	61.8	17.0%
95% Response Time (Minutes)			
@ 15 K ppm H2O	Average	Std. Dev.	% Dev.
0 to 5000 ppm	18.62	3.1	16.2%
500 to 5000 ppm	4.18	4.4	79.8%
95% Recovery Time (Minutes)			
@ 15 K ppm H2O	Average	Std. Dev.	% Dev.
5000 to 500 ppm	1.47	0.0	0.0%
5000 to 0 ppm	2.39	0.0	0.0%

Table 5.6: Figaro 823 and Adsistor Sensor Response to Multiple Gas Excursion Test and Water Excursion Test

Calibrated for Xylene @ 15 K ppm H2O

Time period for changes in concentrations is 30 minutes.

Actual Water (ppm)	Actual Methane (ppm)	Actual Butane (ppm)	Actual Xylene (ppm)	Adsistors Average (ppm)	Adsistors Std. Dev.	Adsistors % Dev.	Figaro 823 Average (ppm)	Figaro 823 Std. Dev.	Figaro 823 % Dev.	Figaro 822 Average (ppm)	Figaro 822 Std. Dev.	Figaro 822 % Dev.	Figaro 812 Average (ppm)	Figaro 812 Std. Dev.	Figaro 812 % Dev.
15002	500	500	100	153.6	8.7	5.7%	298.7	186.0	62.3%	321.1	182.9	57.0%	175.6	22.5	12.8%
15002	500	500	100	157.0	8.5	5.4%	302.3	201.6	66.7%	321.3	185.0	57.6%	175.4	22.3	12.7%
15002	500	500	100	148.6	8.3	5.6%	304.2	211.3	69.5%	322.9	188.6	58.4%	173.7	22.7	13.0%
15002	500	500	100	141.2	8.3	5.9%	306.7	219.2	71.5%	326.0	194.0	59.5%	171.7	23.4	13.6%
15002	4999	500	100	142.2	8.6	6.1%	321.2	234.9	73.1%	342.9	211.5	61.7%	175.9	25.5	14.5%
15002	500	500	100	137.5	8.6	6.3%	308.5	228.3	74.0%	329.0	199.4	60.6%	168.4	24.6	14.6%
15002	500	4999	100	142.3	8.5	6.0%	1042.6	1086.7	104.2%	1048.3	932.3	88.9%	297.4	67.5	22.7%
15002	500	500	100	135.0	9.0	6.6%	292.1	220.0	75.3%	301.8	175.6	58.2%	159.7	22.7	14.2%
15002	500	500	1000	940.6	10.3	1.1%	1720.5	696.1	40.5%	1406.0	398.5	28.3%	1053.1	8.2	0.8%
15002	500	500	100	213.4	12.1	5.7%	280.2	216.8	77.4%	297.1	180.5	60.7%	172.7	24.2	14.0%
15002	500	500	100	196.6	12.6	6.4%	284.7	223.5	78.5%	302.7	187.4	61.9%	157.8	23.7	15.0%
15002	500	500	100	134.4	11.1	8.3%	272.8	186.2	68.3%	295.6	172.1	58.2%	145.6	24.6	16.9%
4999	500	500	100	137.1	13.0	9.5%	157.4	102.4	65.0%	185.7	89.5	48.2%	101.6	22.2	21.8%
1667	500	500	100	131.0	13.9	10.6%	100.1	59.3	59.3%	131.8	54.7	41.5%	77.3	20.0	25.8%
0	500	500	100	127.1	14.5	11.4%	57.6	30.3	52.7%	88.5	32.4	36.6%	55.6	18.1	32.5%
15002	500	500	100	111.3	10.8	9.7%	318.0	247.0	77.7%	342.7	220.3	64.3%	152.5	28.2	18.5%

Table 5.7: Figaro 813 Sensor Response to Multiple Gas Excursion Test and Water Excursion Test

Calibrated for Methane @ 15 K ppm H2O
Time period for changes in concentrations is 30 minutes.

Actual H2O (ppm)	Actual Methane (ppm)	Actual Butane (ppm)	Actual Xylene (ppm)		Figaro 813 Average (ppm)	Std. Dev.	% Dev.
15002	500	500	100		1218.9	122.9	10.1%
15002	500	500	100		1142.5	127.2	11.1%
15002	500	500	100		1098.9	135.7	12.4%
15002	500	500	100		1055.1	150.2	14.2%
15002	**4999**	500	100		6410.8	435.1	6.8%
15002	500	500	100		997.7	145.9	14.6%
15002	500	**4999**	100		6082.6	1411.9	23.2%
15002	500	500	100		863.4	126.9	14.7%
15002	500	500	**1000**		1675.4	280.2	16.7%
15002	500	500	100		913.3	131.4	14.4%
15002	500	500	100		893.6	134.4	15.0%
15002	500	500	100		887.7	154.5	17.4%
4999	500	500	100		484.5	95.2	19.6%
1667	500	500	100		347.1	77.1	22.2%
0	500	500	100		271.9	67.1	24.7%
15002	500	500	100		906.4	159.4	17.6%

5.1 Reproducibility

The Adsistor sensors tested had model parameters and sensor responses within 11% of each other, Table 5.1.

All the Figaro sensors tested in this study showed wide variations in the sensor model parameters and measured responses.

For the Figaro 823 sensors, the spread in percent standard deviation ranged from 15% to 141%, Table 5.2. Similar variations in sensor behavior were observed for the Figaro 822 and 812 sensors, Tables 5.3, and 5.4 respectively.

The Figaro 813 sensors showed a more reproducible response with the spread in percent standard deviation ranging from 3% to 30% when analyzed with methane. Table 5.5.

5.2 Sensitivity

Gas concentration ramp tests were used to determine the test gas to which the sensors were most sensitive. The sensors were then modeled for this target gas.

The Adsistor sensor's measured response to xylene, butane, and methane concentration ramps is plotted in Figure 5.1. The sensor clearly responded to xylene at concentrations over 100 ppm as shown by its increased resistance. The sensor's resistance did not change when exposed to methane and butane at concentrations up to 5000 ppm. Thus, the Adsistor sensors were modeled and calibrated for xylene, and their responses reported in terms of xylene concentration (ppm), Table 5.1.

The Adsistor model does not exactly fit the data indicating that the sensor was not sufficiently sensitive to the lower xylene concentration range. Readings of 62 and 68 ppm xylene, Table 5.1, in the presence of 10 and 30 ppm xylene, respectively, reveal the baseline or zero reading for these sensors. Also, the reading of 233 ppm xylene in the presence of 300 ppm indicate the model is insufficient to truly characterize this sensor. However, the small spread of 3.7 ppm among the 9 Adsistor sensors indicates that the sensors are responding similarly.

A Figaro 823 sensor is plotted with respect to the same xylene, butane, and methane concentration ramps as shown in Figure 5.2. For this sensor, the resistance decreased with respect to all the test gases. However, it is was most sensitive to xylene as seen by the larger changes in resistance at a given concentration level. The Figaro 823 sensors are sensitive enough to measure 10 ppm xylene, Table 5.2, and were therefore modeled and calibrated for xylene.

This sensitivity to xylene was also observed for the Figaro 812 and 822 sensors. Thus, the Figaro 812, 822, and 823 sensors were all modeled and calibrated for xylene.

In the case of the Figaro 813 sensors, they were more sensitive to methane and therefore calibrated as methane sensors with the data tabulated in Tables 5.5 and 5.7.

Figure 5.1: Adsistor Response to Methane, Butane, and Xylene Concentration Ramps @ 15 K ppm H2O

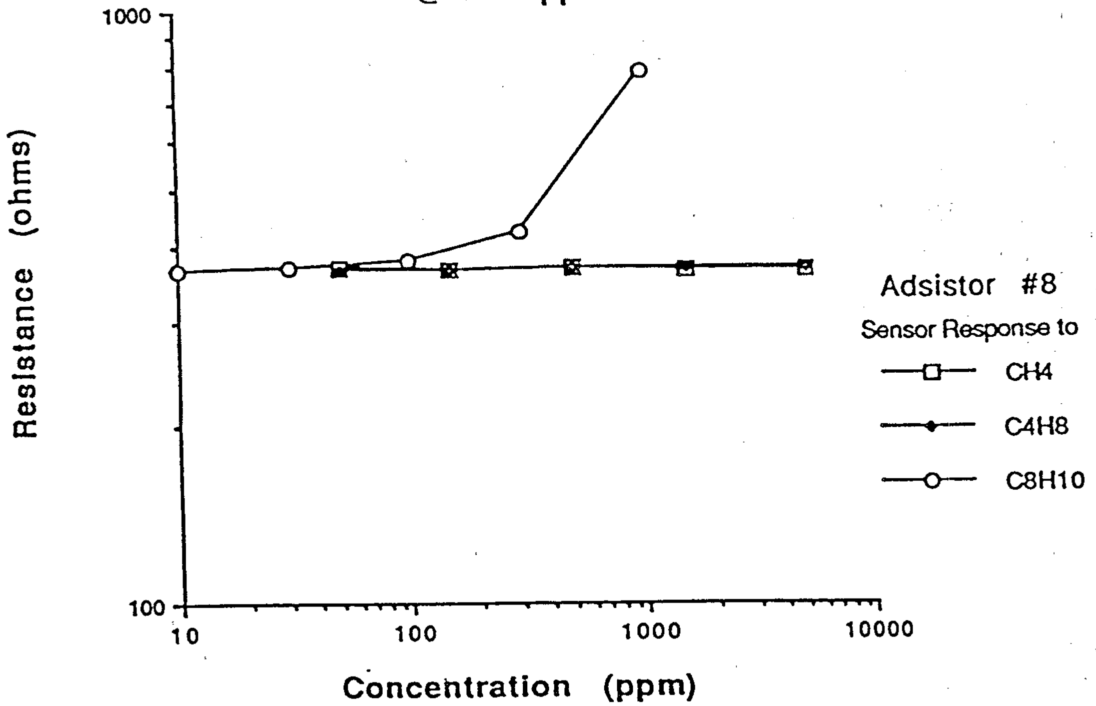
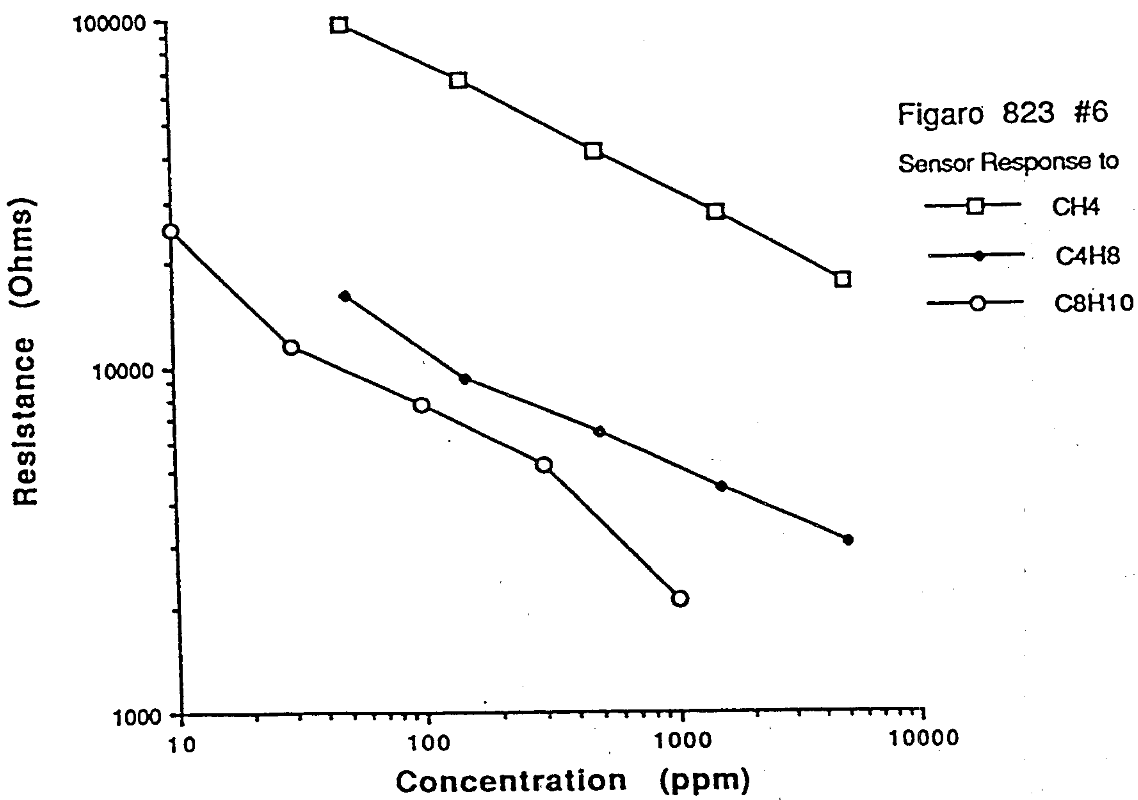


Figure 5.2: Figaro 823 Response to Methane, Butane, and Xylene Concentration Ramps @ 15 K ppm H2O



5.3 Water Vapor Response: Humidity Affects on Sensitivity

Adsistor sensor sensitivity to xylene was not affected by the changes in the level of humidity. This was indicated in Figure 5.3 by the overlapping data points for xylene. These points were taken at the wet (15,000 ppm water vapor) and dry (0 ppm water vapor) conditions and quantified in Table 5.1.

For the Figaro 823 sensor, changes in readings of more than 50% were observed when the humidity varied from the wet to dry conditions. This is shown in Figure 5.4, a resistance versus concentration plot and again in Figure 5.5, a concentration versus time plot. The plotted lines in Figure 5.5 show when the test gases are introduced and to what concentration levels. The sensor response was plotted as in ppm of xylene, both for the dry and wet conditions.

Figure 5.6 plots the response of a Figaro 823 sensor and an Adsistor sensor, computed as ppm xylene, during a water vapor excursion test. For the Figaro 823 sensor, changes in reading of more than 50% were observed when the humidity varied from wet to dry conditions. The Adsistor sensors showed little effect due to short term changes in humidity. These results are quantified in Table 5.2.

5.4 Cross Sensitivity: Selectivity

The selectivity of a sensor relates to how the sensor responds to gases, other than the one it is calibrated for, both individually and in mixtures. If a sensor is perfectly selective, it will respond to only its target gas. If the sensor is not perfectly selective, its cross sensitivity is an indication of how a particular gas could cause a false reading.

The average cross sensitivity response of the Figaro 823 sensors to 5000 ppm methane and 5000 ppm butane, is 24 ppm and 793 ppm respectively, Table 5.2

Figure 5.7 plots a Figaro 823 sensor's response to the Gas Concentration Ramp Test. The sensor's response is computed in ppm of xylene and plotted versus time as the sensor is exposed to the individual test gases. The plotted data shows that when the sensor was exposed to 5000 ppm methane, it measured 13.4 ppm xylene, indicating a very small cross sensitivity to methane. When exposed to 5000 ppm butane, it measured approximately 500 ppm xylene, indicating a cross sensitivity to butane of about 1 to 10.

The Adsistor's cross sensitivity response to 5000 ppm methane and 5000 ppm butane, is 63 ppm and 62 ppm respectively, Table 5.1. As mentioned previously, these values indicate a zero response showing the Adsistor sensors to be insensitive at the concentration tested both to methane and butane.

The sensor cross sensitivity in multiple gases for the Adsistor and Figaro sensors are tabulated in Table 5.6. The Adsistor sensors are selective to xylene even in the presence of a mixture of methane and butane. This was apparent in that the Adsistor's xylene response did not vary even when the concentrations of methane and butane were increased to 5000 ppm.

Figure 5.3: Adsistor Response to Xylene Concentration Ramps @ 15 K ppm H2O and 0 K ppm H2O

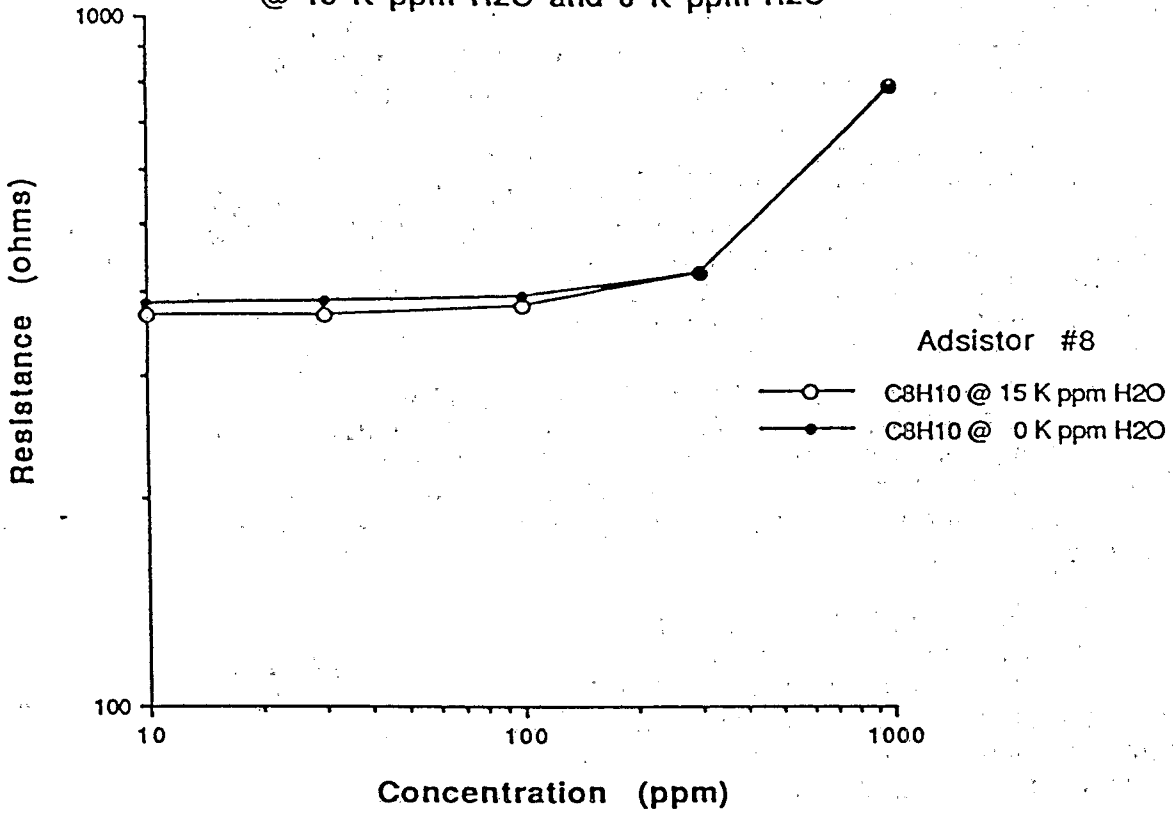


Figure 5.4: Figaro 823 Response to Xylene Concentration Ramps @ 15 K ppm H2O and O K ppm H2O

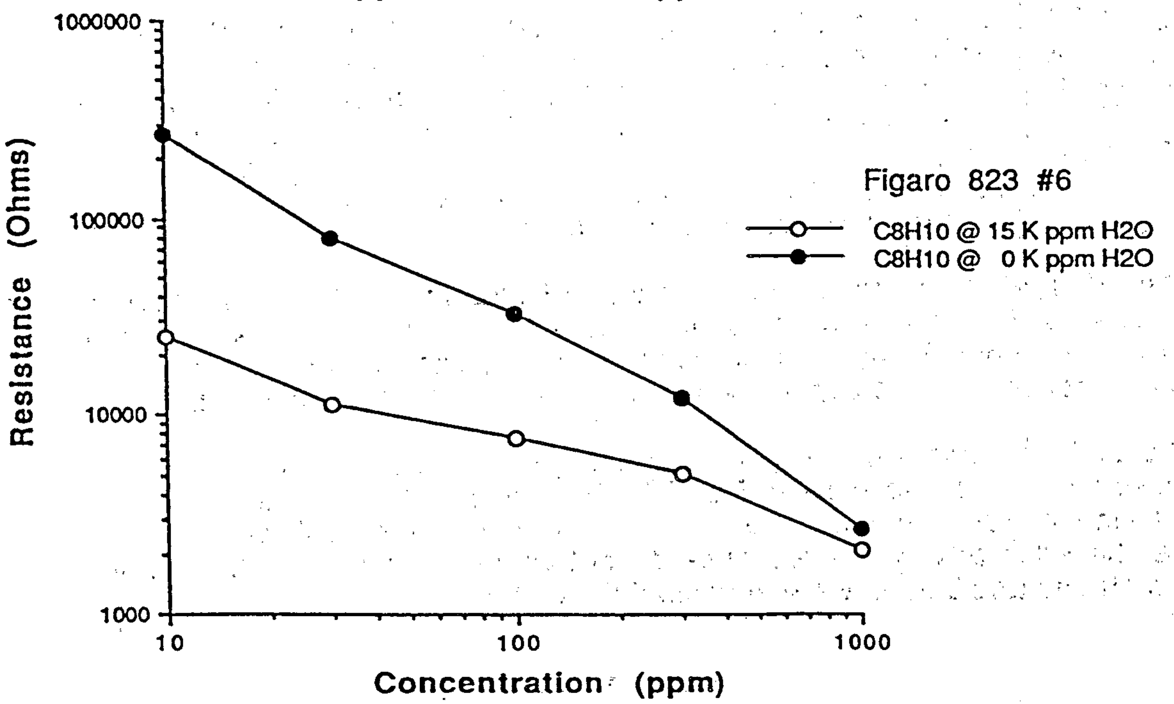


Figure 5.5: Figaro 823 Sensor Response to Xylene Concentration Ramps @ 15 K ppm and O ppm H2O

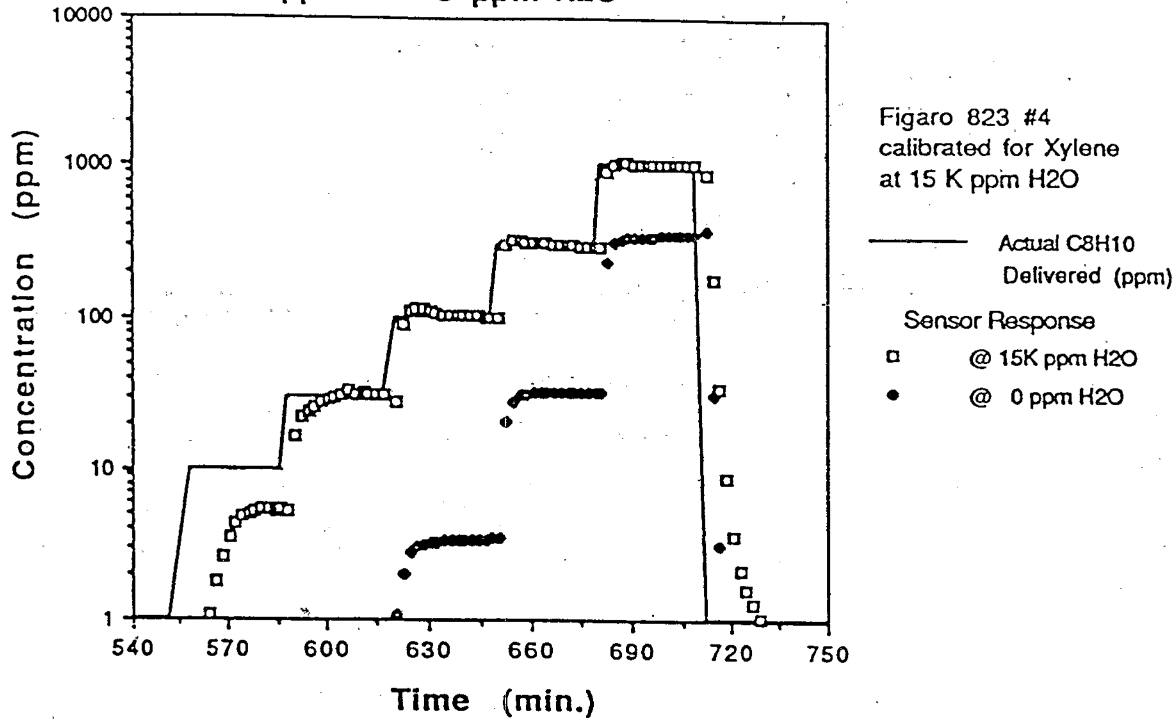


Figure 5.6: Figaro 823 and Adsistor Sensor Response to Changes in Humidity in a Mixture of Methane, Butane, and Xylene

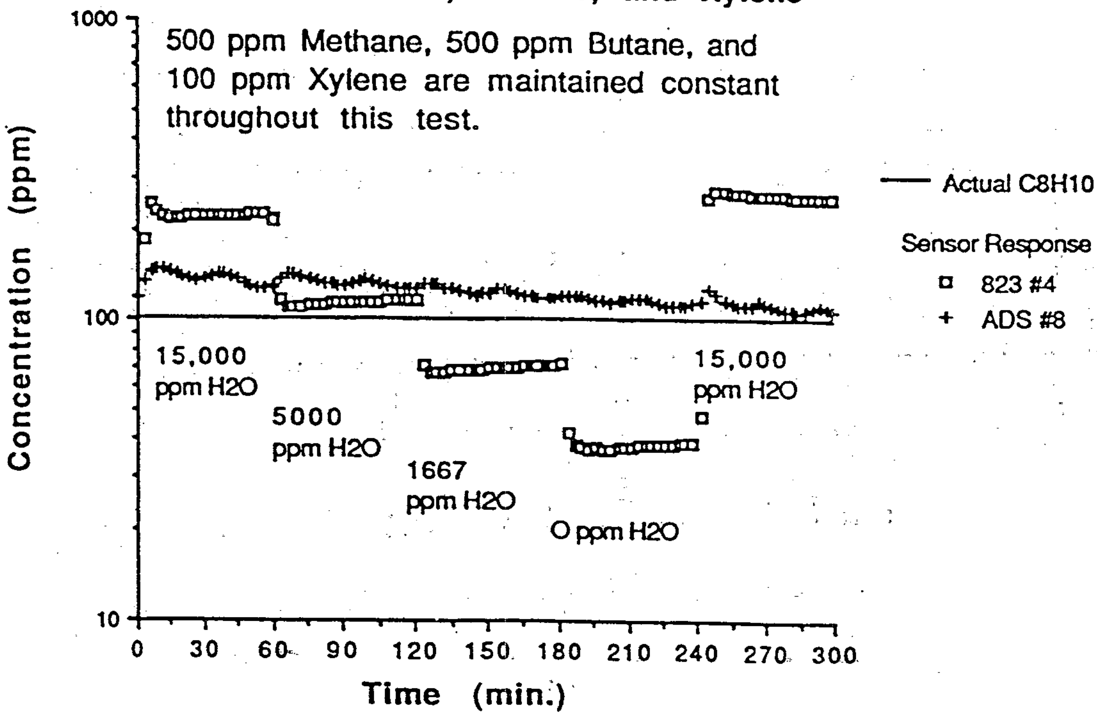
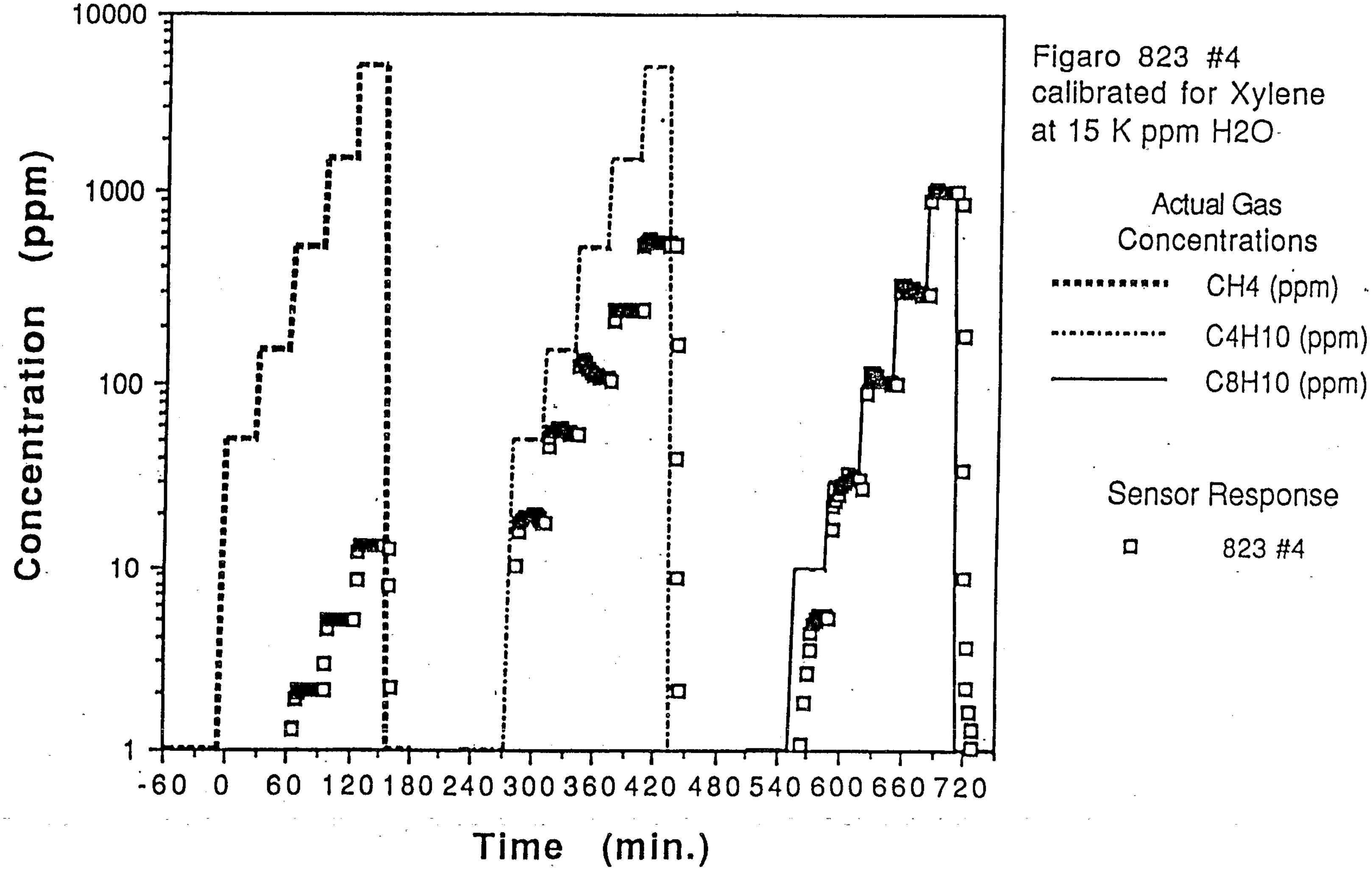


Figure 5.7: Figaro 823 Sensor Response to Methane, Butane, and Xylene Concentration Ramps @ 15 K ppm H2O



The Figaro 823 sensor cross sensitivity to butane was larger in a mixture than would be expected from the tests performed with individual gas ramps. At the background level (500 ppm methane, 500 ppm butane, 100 ppm xylene), the Figaro 823 sensor reads over 300 ppm xylene. This error can be attributed mainly to the presence of the 500 ppm butane. The Figaro 823 sensor was shown to be insensitive to methane by the slight increase in the xylene level as the methane is increased to 5000 ppm. When the butane level was raised to 5000 ppm, the xylene reading increased to over 1000 ppm, and when the xylene level was raised to 1000 ppm, the xylene reading was increased to 1700 ppm.

Figure 5.8 displays these results showing the response of a Figaro 823 sensor and an Adsistor sensor, computed as ppm xylene, during an excursion test.

5.5 Speed of Response and Recovery

Figures 5.9 - 5.11 show the responses of a Figaro 823 and Adsistor sensors to changes in xylene concentration.

The Figaro 823 sensor's 95% response times are higher when changing from 0 ppm to 1000 ppm xylene, 15 minutes, than from when changing from 100 ppm to 1000 ppm, 10 minutes. The recovery time from either 1000 ppm to 0 ppm or 1000 to 100 ppm are about the same at 4 and 3 minutes, respectively.

The Adsistor sensor's 95% response times for the above tests were similar at 7.3 and 7.8 minutes, respectively. The recovery time for the Adsistor sensor was over 30 minutes.

Figure 5.8: Figaro 823 and Adsistor Sensor Response to Mixtures of Methane, Butane, and Xylene

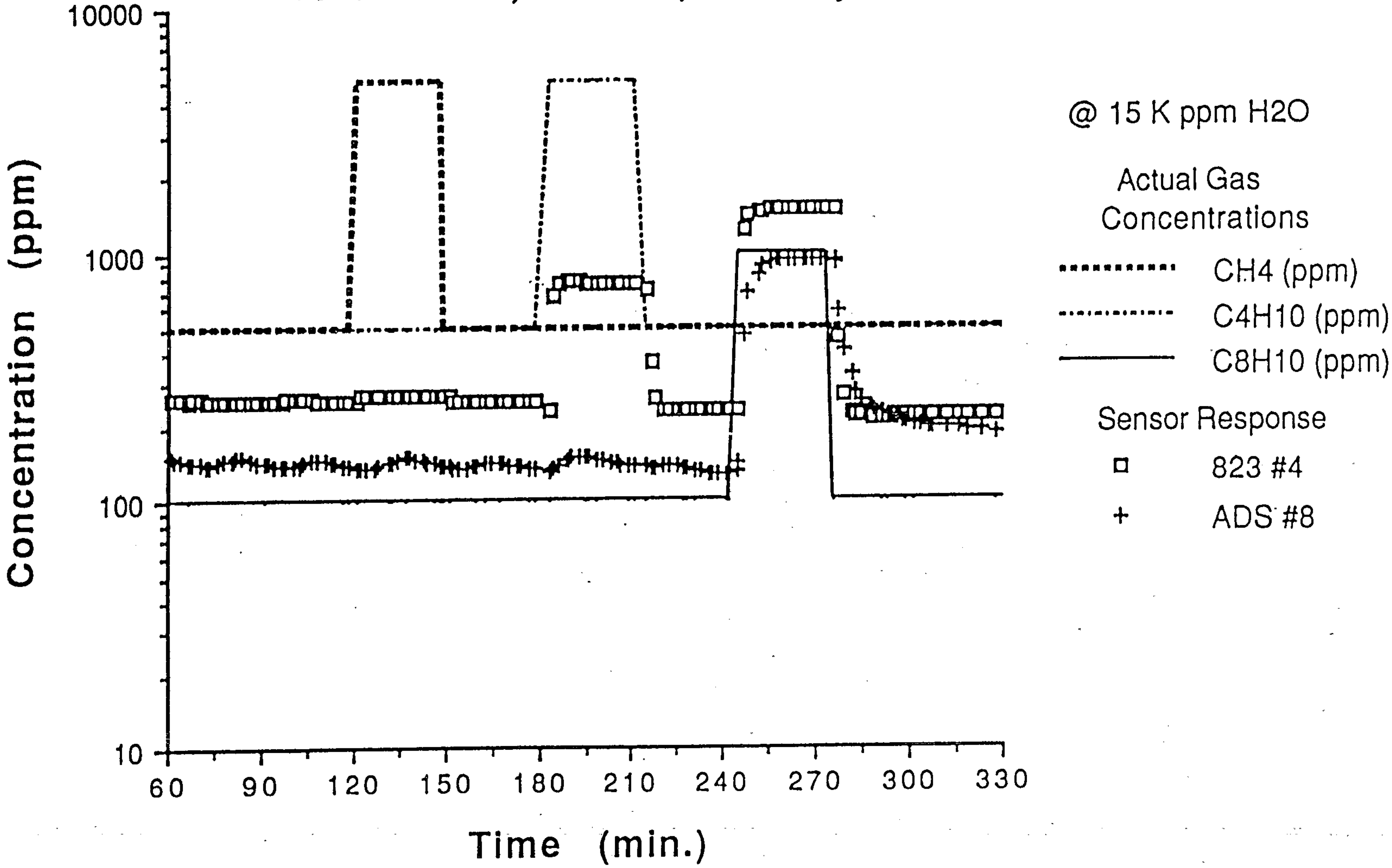


Figure 5.9: Figaro 823 and Adsistor Response to Changes in Xylene Concentration at 15 K ppm H2O

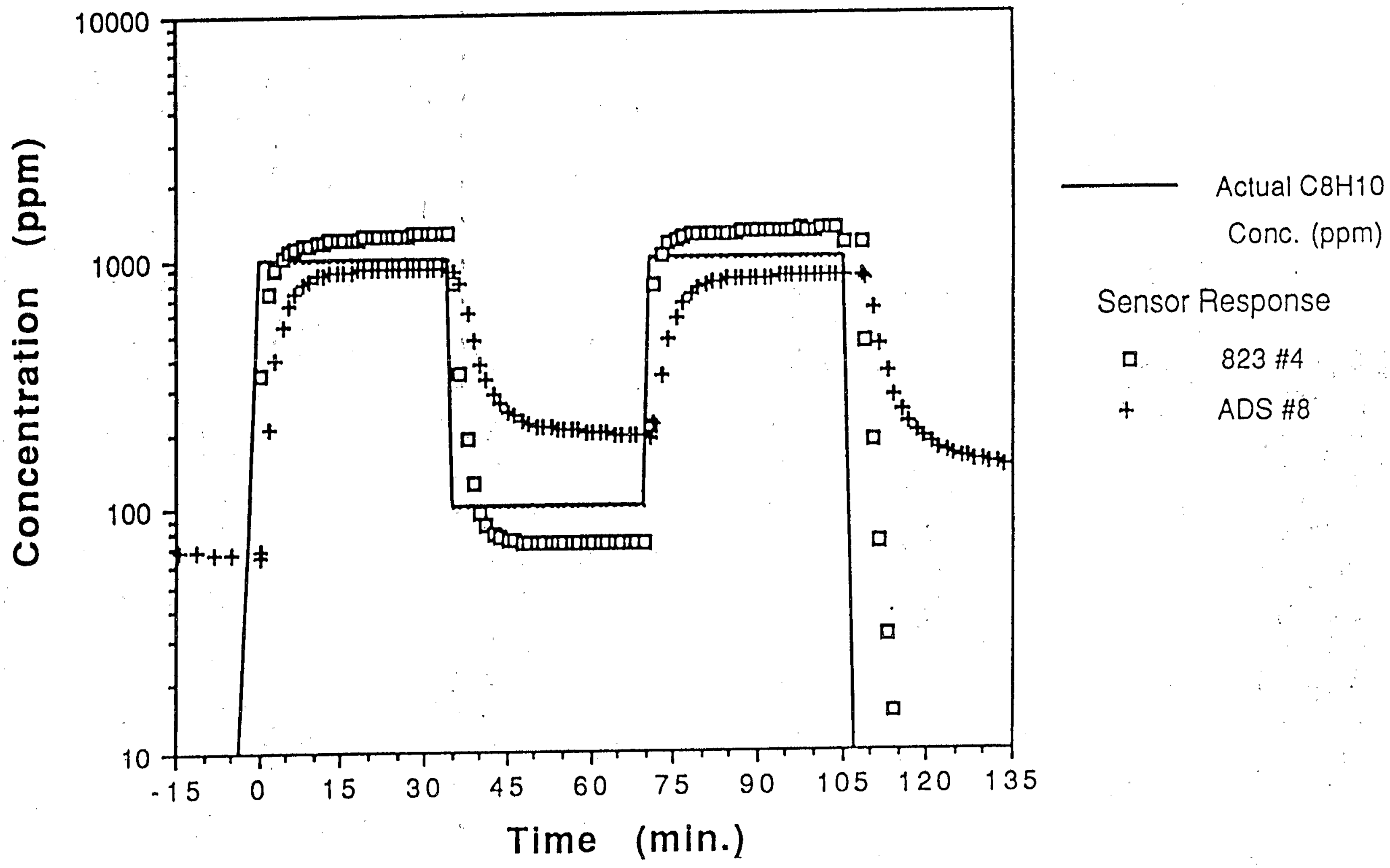


Figure 5.10: Figaro 823 Sensor Responses to Changes in Xylene Concentration at 15 K ppm H2O

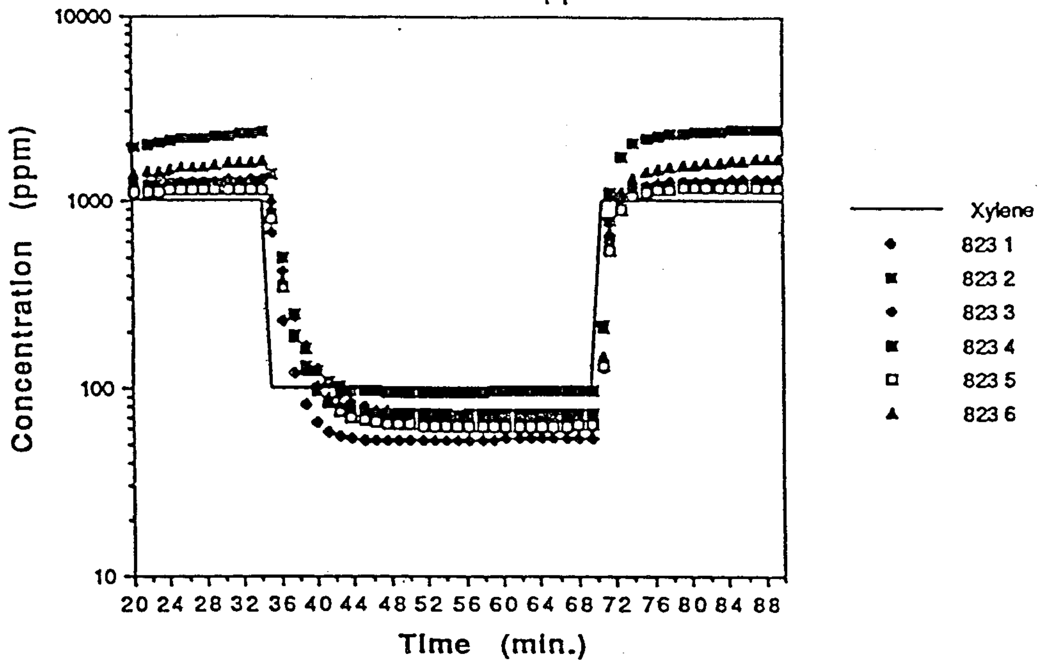
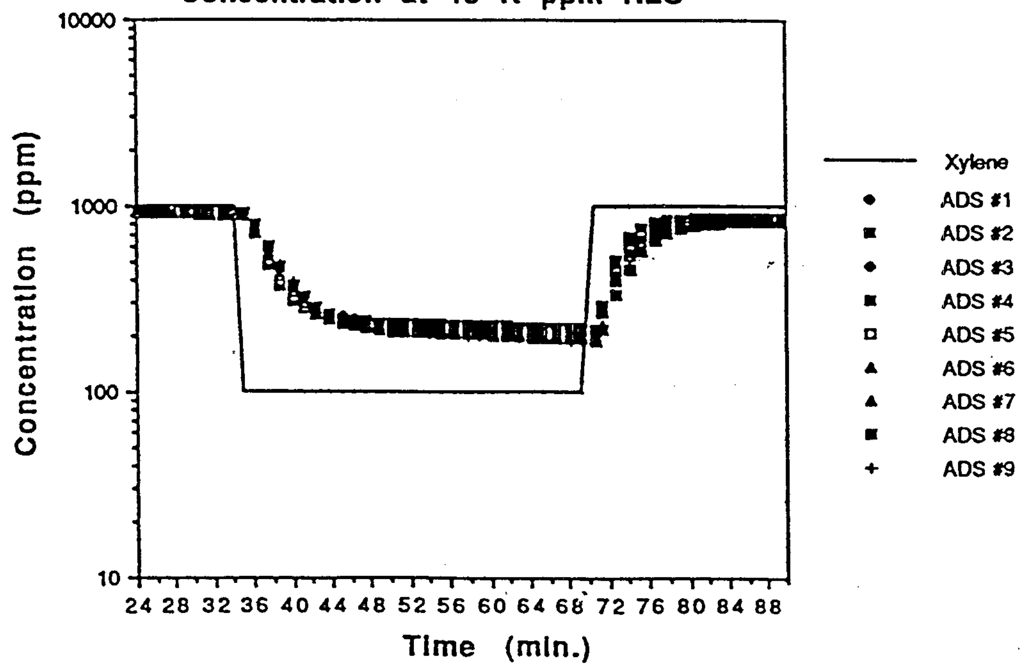


Figure 5.11: Adsistor Sensor Responses to Changes in Xylene Concentration at 15 K ppm H2O



6.0 CONCLUSIONS

Sensor data for two different sensor types, the Figaro MOS sensor and the Adsistor adsorption sensor, have been presented.

Both sensor types appear to have sufficient properties to be used for UST leak detection. Both respond well to xylene, with the Figaro sensor being more sensitive to lower concentrations than the Adsistor. Both sensor types are relatively insensitive to methane, which is the primary interfering compound underground. The observed butane response for the Figaro sensor was not a serious problem since butane is also a component of gasoline. The Adsistor sensors as a group were more reproducible and had a much smaller humidity interference in comparison to the Figaro sensors. These two properties make the Adsistor easier to deal with from an instrumentation and calibration standpoint. However, the Adsistor sensors were observed to have longer xylene recovery times than the Figaro sensor.

Stability is a major sensor specification not yet studied. It plays an important role in determining how a sensor is employed in UST monitoring. If a sensor changes with time, independent of the actual conditions, it could lead to false alarms and/or not being able to detect a leak. It is recommended that a stability test be undertaken to determine the calibration periods of the sensors and how their characteristics change with time.

7.0 RECOMMENDATIONS

This report demonstrates that the properties of different gas sensor technologies can be evaluated for the UST environment. However, more work is needed to thoroughly examine the sensing properties of these two sensor technologies.

It is recommended that:

1) Sensor stability should be characterized.

2) Sensors should be tested to determine their response to variations in oxygen concentration to simulate bio-degradation occurring at the UST sites [4].

3) Sensors should be tested to determine their response to variations in concentration of UTS product or synthetic fuels to improve the simulation of the UST environment.

4) Additional gas sensor technologies should be evaluated and their responses analyzed for the UST environment.

REFERENCES

1) Figaro Taguchi sensors are a product of Figaro Engineering of Japan represented by Figaro USA, Inc., P. O. Box 357, Wilmette, IL 60091.

2) Adsistor Vapor Sensors are products of Adsistor Technology, P. O. Box 51160, Seattle, WA 98115.

3) Schlez, C., "Background Hydrocarbon Vapor Concentration Study for Underground Fuel Storage Tanks," Draft Final Report for U.S. EPA, Contract No. 68-03-3409, February 29, 1988.

4) Personal communication with Philip B. Durgin, Ph.D., U. S. Environmental Protection Agency, Environmental Monitoring Systems Laboratory, Las Vegas, NV, November 1990. Presently at Vender-Root Company.

5) Grace, R., Guzman, M., Portnoff, M., Runco, P., Yannopoulos, "Computational Enhancement of MOS Gas Sensor Selectivity," P-33, Proceedings of the Third International Meeting on Chemical Sensors, Cleveland, OH, September,1990.

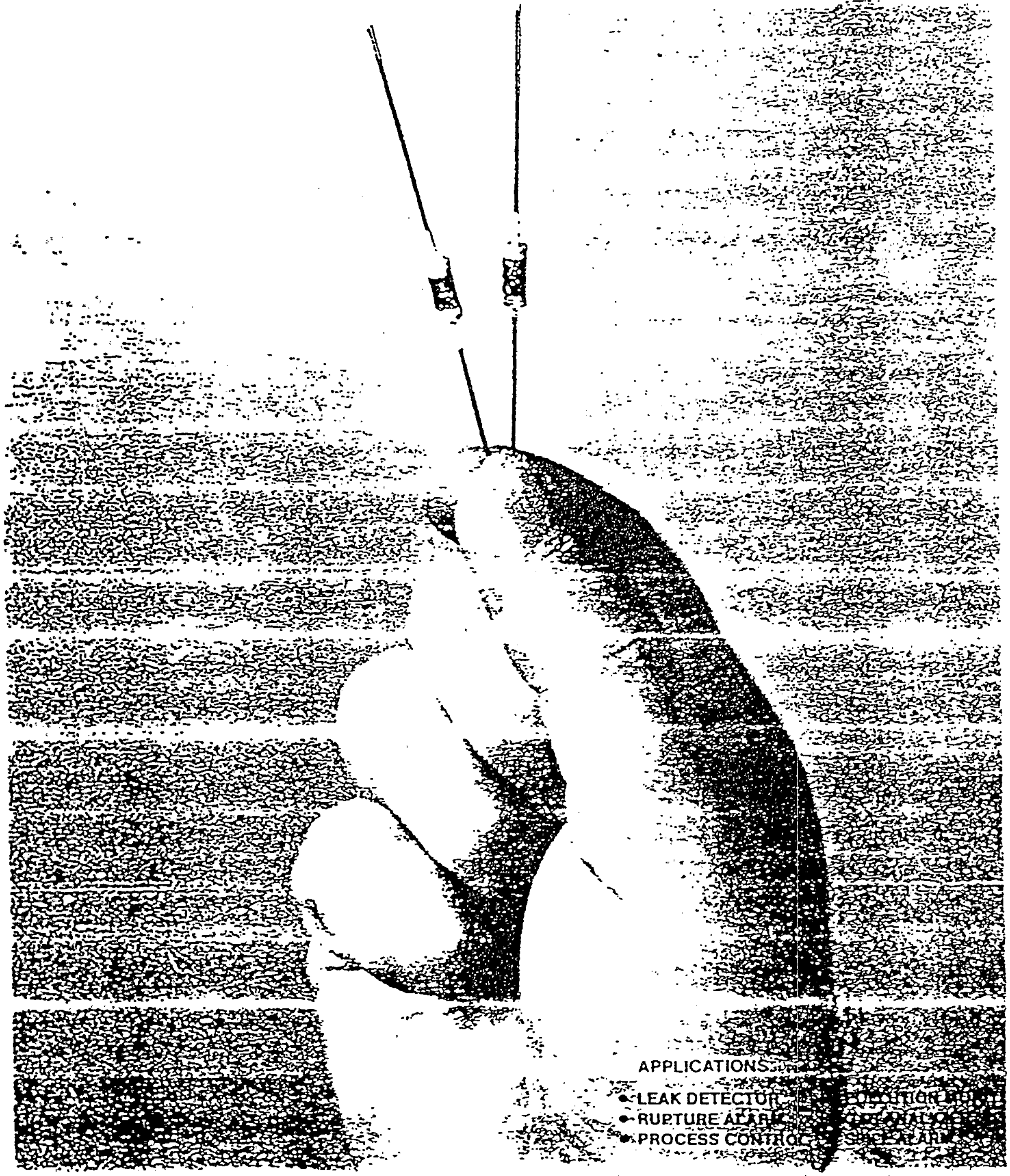
6) Dolan, J., Jordan, W., "Detection Device", U. S. Patent # 3,045,198, July 17, 1962.

APPENDIX A

Adsistor and Figaro Sensor Product Literature

ADSISTOR™

VAPOR SENSOR



Adsorption Sensitive Resistor (Adsistor™)

Unlike other solid state sensors, the Adsistor does not use a hot element and has excellent repeatability and stability. This combined with extremely low power requirements make the Adsistor well suited for use a gas concentration transducer in conjunction with computers, data loggers, medical gas analyzers, freon and halogenated hydrocarbon detectors, portable organophosphate detectors, and explosive mixture detectors.

The Adsistor sensor is sensitive to hundreds of gases and vaporized liquids which allows for a wide variety of applications. Some current applications include fuel cell rupture alarms on airborne military vehicles, marine vessels, and in service stations. The Adsistor's rugged construction and insensitivity to water vapor make it ideal for use in outdoor and other high humidity environments.

The electrical resistance measured across an Adsistor is determined by the amount and type of gas molecules adsorbed to its surface. (Adsorption is the adhesion of gas molecules to the surface of a solid. The tendency of a gas to be adsorbed is proportional to the magnitude of its van der Waals "a" constant.)

In normal ambient conditions an Adsistor has a characteristic base resistance which is determined by its method of construction. When the Adsistor is exposed to gas or vapor, molecules of material are adsorbed upon the Adsistor's surface. A dramatic increase in resistance can result depending upon the operating medium, the van der Waals "a" constant of the intruding gas, its liquefaction temperature, and the concentration of the gas.

For most gases the Adsistor conforms to the relation.

$R = R_b 10^{C/K}$, Temp = constant

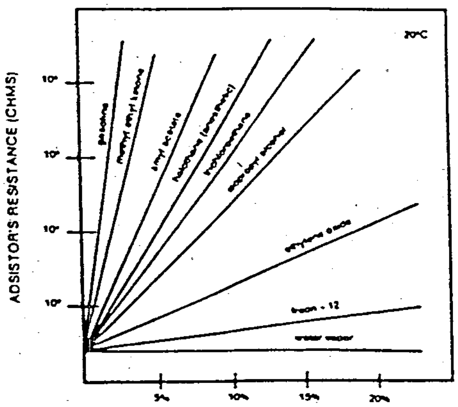
Where R is the measured resistance; R_b is the base resistance prior to exposure; C is the concentration of the intruding gas; and K is a constant depending on the gas and the ambient temperature. In figure 1 are graphed resistance vs. concentrations for various substances.

Changes in ambient temperature make a difference in the resistance developed for a given concentration of a gas. In figure 2 are graphed resistances vs. concentrations for trichloroethane at various temperatures.

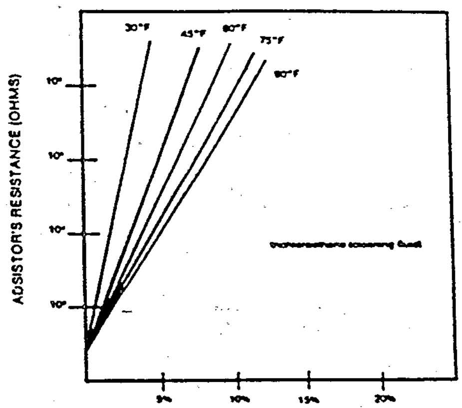
Response to an increase in concentration of an intruding gas is very rapid. The effect of a decrease in concentration occurs more slowly. Time is required for the gas molecules to desorb from the Adsistor's surface.

Base resistance (R) response to changing temperature is linear, provided that the change is not rapid.

See figure 3.



VAPOR CONCENTRATION FIGURE 1.



VAPOR CONCENTRATION FIGURE 2.

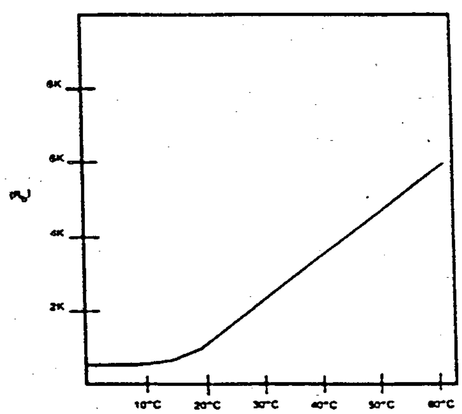


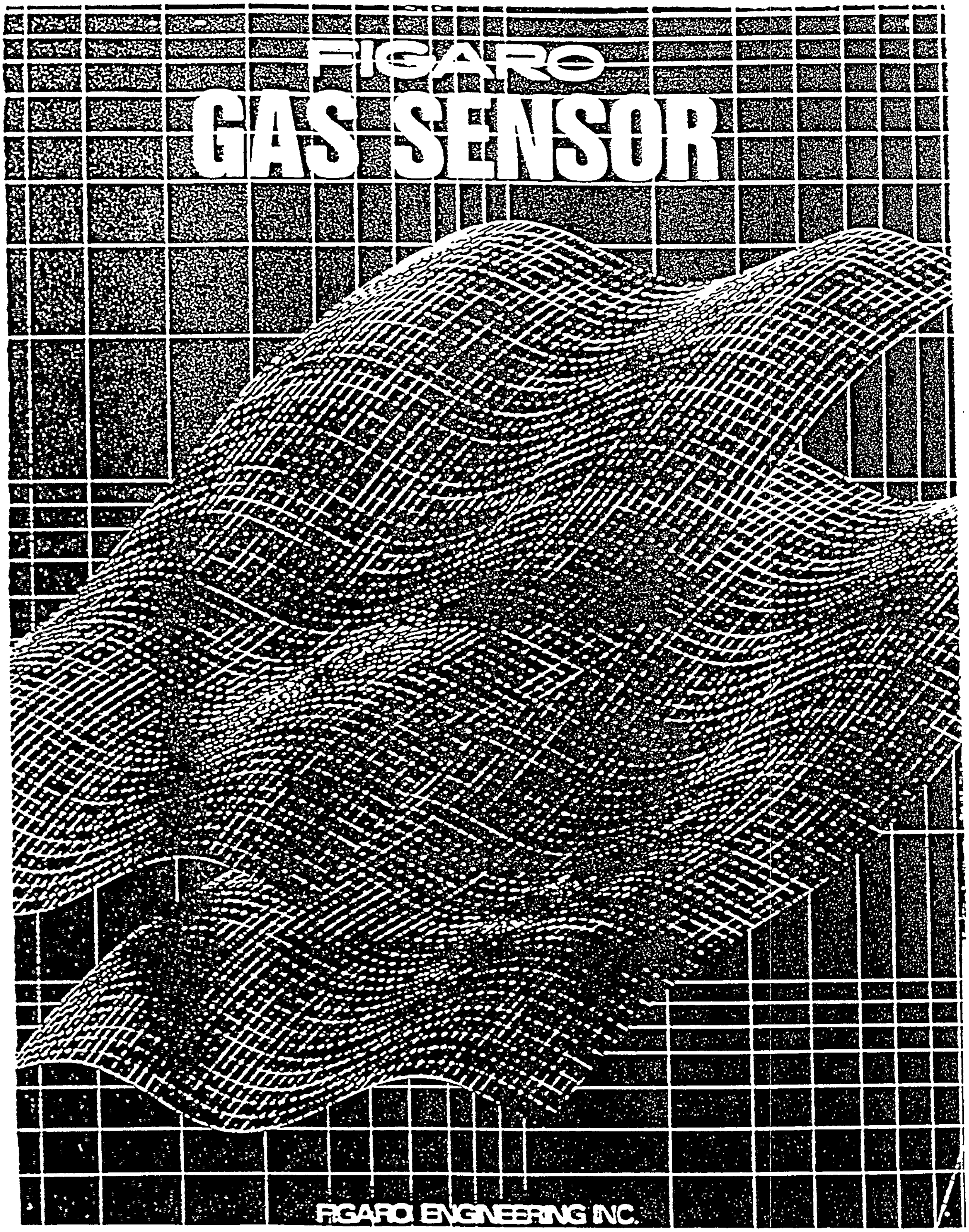
FIGURE 3.

ADSISTOR™
VAPOR SENSOR

APPLICATIONS:

- **LEAK DETECTOR**
- **RUPTURE ALARM**
- **PROCESS CONTROL**
- **POLLUTION MONITOR**
- **GAS ANALYZER**
- **SPILL ALARM**

ADSISTOR TECHNOLOGY™ 206/365-9110
~~5600½ N.E. 65th Street~~ • Seattle, Washington 98115 • Tel: ~~(206) 523-0406~~
Mailing Address P.O. Box 51160 • Seattle, Washington 98115


FIGARO
GAS SENSOR
FIGARO ENGINEERING INC.

COMBUSTIBLE GAS SENSOR (100V CIRCUIT VOLTAGE)

TGS 109

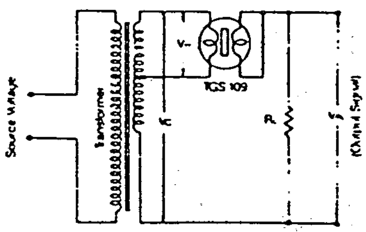
Features

- Large output signal to drive an alarm circuit directly.
- Long-term stability.

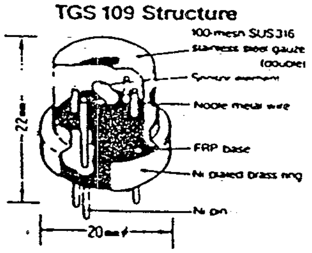
Applications

- Domestic and industrial gas detectors for propane, methane and other combustible gases.

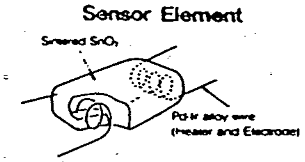
Basic Measuring Circuit

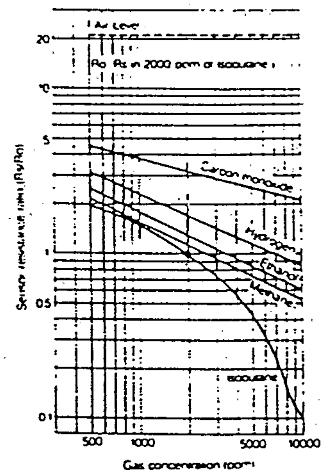


TGS 109 Structure



Sensor Element





TGS 109 Sensitivity Characteristics
(Typical data)

Specifications

Model	TGS 109
Circuit conditions	Circuit voltage (V_C): 100V A.C. or D.C. Heater voltage (V_H): 1.0V A.C. or D.C. Load resistance (R_L): 4KΩ Heater power consumption (P_H): Approx. 440mW
Detection range	500 ~ 10,000 ppm of propane, methane

*Please contact Figaro for other detectable gases.

COMBUSTIBLE GAS SENSOR (24V MAX CIRCUIT VOLTAGE)

TGS 813, TGS 816

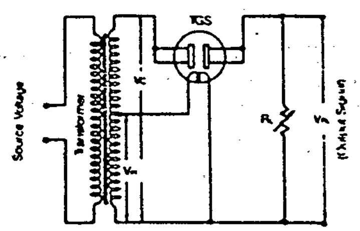
Features

- Long-term stability.
- Small influence of noise gases.
- Excellent repeatability.
- Versatile circuit voltage.

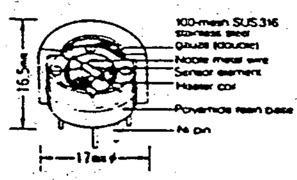
Applications

- Domestic and industrial gas detectors for propane, methane and other combustible gases.

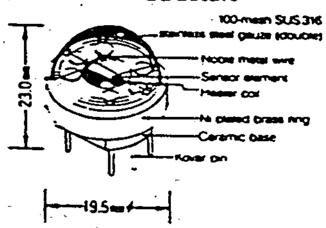
Basic Measuring Circuit



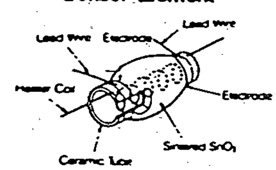
TGS 813 Structure

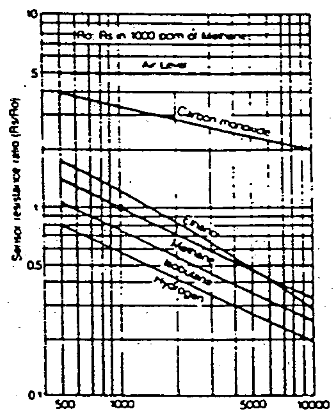


TGS 816 Structure



Sensor Element





TGS 813 Sensitivity Characteristics
(Typical data)

Specifications

Model	TGS813 (Plastic housing)	TGS816 (Ceramic housing)
Circuit conditions	Circuit voltage (V_C): 24V max. A.C. or D.C. Heater voltage (V_H): 5V A.C. or D.C. Heater power consumption (P_H): Approx. 830mW	
Detection range	500 ~ 10,000 ppm of propane, methane	

*Please contact Figaro for other detectable gases.

HIGH SENSITIVITY TO ORGANIC VAPOURS

TGS 822, TGS 823

Feature

- High sensitivity to organic vapours such as alcohol.

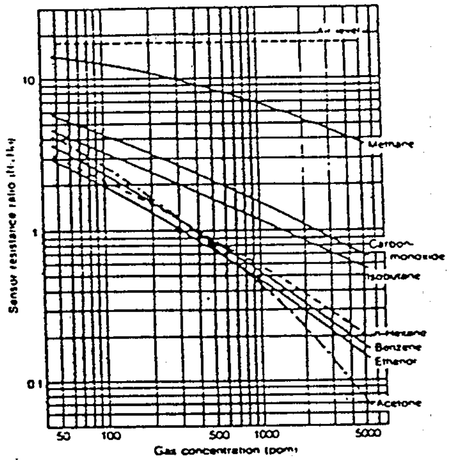
Applications

- Breath alcohol detectors, organic vapour monitors and industrial gas detectors.

Specifications

Model	TGS 822	TGS 823 (Ceramic housing)
Structure	Same as TGS 813	Same as TGS 816
Circuit conditions	Circuit voltage (V_C): 24V max. A.C. or D.C. Heater voltage (V_H): 5V A.C. or D.C. Heater power consumption (P_H): Approx. 650mW	
Detectable gases and the detection range	Ethanol 50 ~ 10,000 ppm n-Pentane 50 ~ 5,000 ppm n-Hexane 50 ~ 5,000 ppm Benzene 50 ~ 5,000 ppm Acetone 50 ~ 5,000 ppm Methanol 50 ~ 5,000 ppm Methyl ethyl ketone 50 ~ 5,000 ppm	

*Please contact Figaro for other detectable gases.



TGS 822 Sensitivity Characteristics

HIGH SENSITIVITY TO AMMONIA (NH_3)

TGS 824

Feature

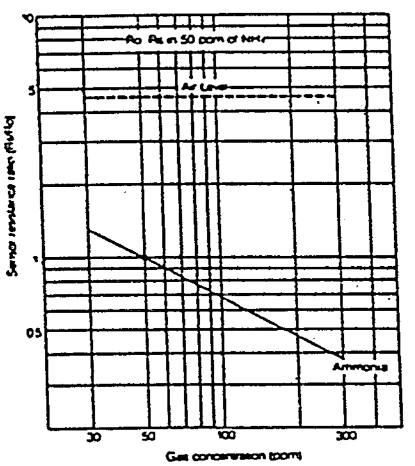
- High sensitivity to ammonia.

Applications

- Industrial detectors for ammonia.
- Automatic control in ventilation systems for poultry sheds and livestock farms.

Specifications

Model	TGS 824 (Ceramic housing)
Structure	Same as TGS 816
Circuit conditions	Circuit voltage (V_C): 24V max. A.C. or D.C. Heater voltage (V_H): 5V A.C. or D.C. Heater power consumption (P_H): Approx. 420mW
Detection range	30 ~ 300 ppm of NH_3



TGS 824 Sensitivity Characteristics

(Typical data)

HIGH SENSITIVITY TO HYDROGEN SULFIDE (H_2S)

TGS 825

Feature

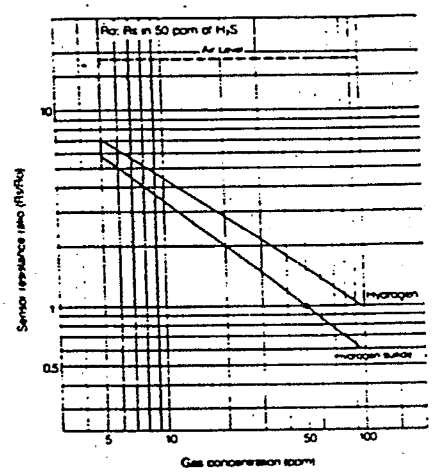
- High sensitivity to hydrogen sulfide.

Application

- Industrial detectors for toxic gases.

Specifications

Model	TGS 825 (Ceramic housing)
Structure	Same as TGS 816
Circuit conditions	Circuit voltage (V_C): 24V max. A.C. or D.C. Heater voltage (V_H): 5V A.C. or D.C. Heater power consumption (P_H): Approx. 650mW
Detection range	5 ~ 100 ppm of H_2S



TGS 825 Sensitivity Characteristics

(Typical data)

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APPENDIX B

Adsistor and Figaro Sensor Test Data

Table B1: Adsistor Measurements

H20	CH4	C4H10	C8H10	C8H10	C8H10	C8H10	C8H10	C8H10	C8H10	C8H10	C8H10	C8H10			
	CALIBRATED FOR XYLENE 100,1000														
				ADS #1	ADS #2	ADS #3	ADS #4	ADS #5	ADS #6	ADS #7	ADS #8	ADS #9	Average	Std. Dev.	% Dev.
ppm	ppm	ppm	ppm												
		K		2736.1	3409.6	2880.4	3313.0	3375.1	2664.4	3043.4	2819.9	2647.6	2987.7	308.3	10.3%
		Rb		393.4	317.6	297.8	327.3	316.1	390.0	351.3	350.2	376.6	346.7	34.5	10.0%
15002	0	0	0	71.6	71.8	59.4	66.8	63.6	65.8	68.2	64.7	61.3	65.9	4.2	6.4%
15002	50	0	0	71.6	71.8	58.6	66.0	62.7	64.9	67.5	64.7	60.4	65.4	4.5	6.9%
15002	150	0	0	69.1	68.7	57.0	62.6	59.6	63.2	64.6	61.0	57.8	62.6	4.3	6.9%
15002	500	0	0	70.8	69.6	57.8	63.9	60.5	63.2	65.7	62.7	59.6	63.8	4.4	6.9%
15002	1500	0	0	68.2	67.8	55.0	61.8	58.7	61.0	63.6	60.4	57.2	61.5	4.5	7.3%
15002	4999	0	0	69.1	68.7	57.8	62.6	60.5	62.4	64.6	62.0	58.7	62.9	4.0	6.3%
15002	0	0	0	65.6	65.6	53.4	59.7	57.4	60.1	61.8	59.4	55.5	59.8	4.1	6.9%
15002	0	0	0	66.5	66.5	54.2	60.9	57.4	60.1	62.9	59.4	56.4	60.5	4.3	7.1%
15002	0	0	0	63.9	64.7	52.6	58.8	54.7	58.4	61.1	57.7	53.7	58.4	4.3	7.3%
15002	0	0	0	68.2	69.6	58.6	63.9	61.8	63.2	66.4	63.7	60.4	64.0	3.6	5.6%
15002	0	50	0	62.2	63.4	51.4	56.7	54.7	56.7	60.0	57.7	53.2	57.3	4.0	7.0%
15002	0	150	0	66.5	68.7	57.0	61.8	59.6	61.8	64.6	62.0	58.7	62.3	3.8	6.0%
15002	0	500	0	71.6	72.7	63.8	67.7	65.8	67.4	68.2	64.7	61.9	67.1	3.5	5.3%
15002	0	1500	0	69.1	69.6	60.2	64.7	62.7	64.1	64.6	62.7	58.7	64.0	3.6	5.6%
15002	0	4999	0	65.6	66.5	57.8	60.9	58.7	61.0	64.6	62.7	58.7	61.8	3.2	5.2%
15002	0	0	0	63.1	64.7	54.2	57.6	55.6	58.4	61.8	58.7	55.5	58.8	3.6	6.2%
15002	0	0	0	63.1	65.6	55.8	59.7	57.4	58.4	62.9	60.4	56.4	59.9	3.3	5.6%
15002	0	0	0	61.6	64.7	55.0	58.8	55.6	56.7	61.8	59.4	55.5	58.8	3.4	5.8%
15002	0	0	0	67.3	69.6	62.2	64.7	63.6	64.1	65.7	62.7	60.4	64.5	2.8	4.3%
15002	0	0	10	64.8	66.5	58.6	60.9	59.6	61.8	62.9	60.4	57.8	61.5	2.8	4.6%
15002	0	0	30	70.8	71.8	65.4	67.7	66.7	67.4	69.3	67.0	65.0	67.9	2.3	3.4%
15002	0	0	100	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0%
15002	0	0	300	231.8	228.1	239.6	232.7	238.0	231.6	231.1	231.6	235.6	233.3	3.7	1.6%
15002	0	0	1000	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	0.0	0.0%
15002	0	0	0	187.5	203.9	176.3	201.3	188.3	183.7	188.0	182.6	173.5	187.2	10.1	5.4%
0	0	0	0	150.0	173.9	122.7	154.7	149.4	135.6	153.7	138.7	131.5	145.6	15.2	10.5%
0	50	0	0	153.2	176.8	127.2	158.7	153.2	139.1	156.7	141.2	133.9	148.9	15.1	10.1%
0	150	0	0	149.2	172.7	123.4	154.7	150.2	135.6	153.7	138.7	130.7	145.4	14.9	10.3%
0	500	0	0	143.4	166.5	117.3	147.6	143.1	130.1	148.3	133.4	124.9	139.4	14.7	10.5%
0	1500	0	0	140.9	163.5	114.6	144.8	140.2	127.4	146.3	130.9	123.3	136.9	14.6	10.6%
0	4999	0	0	138.3	161.5	113.1	141.6	138.1	125.8	143.6	129.0	121.1	134.7	14.3	10.6%
0	0	0	0	142.5	164.4	118.5	146.8	141.8	129.3	145.6	130.9	124.1	138.2	14.0	10.1%
0	0	0	0	139.1	161.5	113.9	142.8	138.9	125.8	141.9	129.0	120.3	134.8	14.2	10.6%
0	0	0	0	140.9	163.5	116.6	145.6	141.0	128.5	143.6	130.9	122.5	137.0	14.1	10.3%
0	0	0	0	139.9	162.3	115.8	143.6	140.2	126.6	142.6	129.9	121.1	135.8	14.1	10.3%
0	0	50	0	132.6	155.2	107.7	135.6	131.7	119.4	137.1	123.9	115.3	128.7	14.0	10.9%
0	0	150	0	130.7	153.1	106.2	133.6	128.7	117.8	134.4	121.4	113.6	126.6	13.8	10.9%
0	0	500	0	131.5	153.1	107.0	135.6	129.6	118.6	135.1	122.4	114.5	127.5	13.7	10.7%
0	0	1500	0	134.2	156.0	109.7	137.6	133.0	121.0	137.1	123.9	116.1	129.9	13.9	10.7%
0	0	4999	0	135.8	155.2	110.4	137.6	133.8	121.8	138.2	125.5	118.6	130.8	13.2	10.1%
0	0	0	0	126.6	146.8	101.6	128.4	124.5	114.6	129.7	117.0	109.8	122.1	13.2	10.8%
0	0	0	0	128.3	148.9	104.3	130.4	126.6	115.4	129.7	117.9	111.1	123.6	13.1	10.6%
0	0	0	0	127.5	146.8	103.5	129.6	125.8	114.6	129.7	117.9	109.8	122.8	12.9	10.5%

Table B1: Adsistor Measurements Con't

H20	CH4	C4H10	C8H10	C8H10 ADS #1	C8H10 ADS #2	C8H10 ADS #3	C8H10 ADS #4	C8H10 ADS #5	C8H10 ADS #6	C8H10 ADS #7	C8H10 ADS #8	C8H10 ADS #9	Average	Std. Dev.	% Dev.
ppm	ppm	ppm	ppm												
0	0	0	0	123.4	143.8	98.1	125.6	121.5	110.6	125.9	114.4	105.6	118.8	13.4	11.3%
0	0	0	10	123.4	143.8	98.8	126.4	121.5	111.4	124.9	113.5	106.4	118.9	13.1	11.1%
0	0	0	30	130.7	149.7	107.7	133.6	129.6	118.6	132.4	121.4	113.6	126.4	12.5	9.9%
0	0	0	100	144.2	161.5	121.9	145.6	141.8	130.9	145.6	133.4	126.6	139.0	12.1	8.7%
0	0	0	300	259.3	269.5	243.1	256.8	260.7	246.3	247.7	238.5	239.8	251.3	10.7	4.3%
0	0	0	1000	997.5	1015.6	999.2	996.0	1005.1	1003.4	986.0	985.4	990.4	997.6	9.7	1.0%
0	0	0	0	221.8	250.7	200.2	230.4	227.7	213.7	217.1	207.3	196.8	218.4	16.7	7.6%
15002	0	0	0	155.9	174.8	144.6	166.9	154.4	156.0	148.3	149.9	146.1	155.2	10.0	6.4%
15002	500	0	0	145.0	165.6	134.0	156.7	143.1	145.4	139.9	142.1	138.0	145.5	9.8	6.7%
15002	0	0	0	151.6	171.9	141.2	163.0	151.5	152.7	143.6	146.2	142.9	151.6	10.1	6.7%
15002	0	500	0	144.2	164.4	132.5	153.9	141.8	143.8	138.8	142.1	137.2	144.3	9.5	6.6%
15002	0	0	0	144.2	164.4	132.5	154.7	141.8	143.8	137.1	141.2	135.6	143.9	10.0	6.9%
15002	0	0	100	173.5	190.4	166.8	183.2	173.1	173.8	162.3	167.7	166.1	173.0	8.9	5.2%
15002	0	0	0	128.3	147.6	119.2	138.4	125.8	129.3	121.5	125.5	121.1	128.5	9.2	7.1%
15002	500	500	100	154.3	170.6	147.2	163.8	152.3	154.5	143.6	149.0	146.9	153.6	8.7	5.7%
15002	500	500	100	157.5	172.7	152.8	168.1	156.5	157.6	146.3	151.4	150.1	157.0	8.5	5.4%
15002	500	500	100	149.2	165.6	141.9	157.9	146.0	148.8	139.9	145.6	142.9	148.6	8.3	5.6%
15002	500	500	100	141.7	158.1	134.0	150.8	138.1	141.4	132.4	138.7	135.6	141.2	8.3	5.9%
15002	4999	500	100	142.5	159.4	134.0	152.7	140.2	142.2	133.4	139.3	136.4	142.2	8.6	6.1%
15002	500	500	100	137.4	155.2	129.9	147.6	133.8	137.2	128.6	135.3	132.3	137.5	8.6	6.3%
15002	500	4999	100	142.5	159.4	135.2	152.7	138.9	142.2	133.4	139.3	137.2	142.3	8.5	6.0%
15002	500	500	100	135.8	151.8	128.0	146.8	133.0	135.6	124.9	130.9	128.2	135.0	9.0	6.6%
15002	500	500	1000	952.4	958.4	941.2	946.6	932.1	941.5	929.3	929.4	934.6	940.6	10.3	1.1%
15002	500	500	100	216.8	236.1	208.7	228.6	210.1	213.0	205.9	203.2	198.4	213.4	12.1	5.7%
15002	500	500	100	199.3	220.5	186.9	213.5	191.5	196.6	190.0	187.7	183.9	196.6	12.6	6.4%
15002	0	0	0	124.2	146.8	109.7	137.6	117.2	120.2	117.7	118.9	112.0	122.7	12.1	9.8%
15002	500	500	100	135.8	155.2	126.1	150.8	128.7	133.3	125.9	128.4	125.7	134.4	11.1	8.3%
4999	500	500	100	143.4	160.2	122.7	152.7	136.8	134.8	132.4	128.4	122.5	137.1	13.0	9.5%
1667	500	500	100	137.4	156.0	115.8	146.8	133.0	125.8	128.0	120.5	115.3	131.0	13.9	10.6%
0	500	500	100	132.6	155.2	111.2	141.6	128.7	121.8	124.9	117.0	111.1	127.1	14.5	11.4%
15002	500	500	100	114.9	131.0	100.8	125.6	103.9	113.0	103.8	105.8	103.1	111.3	10.8	9.7%
15002	0	0	0	69.9	85.5	61.0	81.8	59.6	70.5	59.3	66.3	61.3	68.4	9.7	14.2%
15002	0	0	1000	915.7	923.0	913.8	918.1	903.4	917.1	895.9	897.5	908.7	910.4	9.6	1.1%
15002	0	0	100	205.2	218.5	205.2	219.5	197.6	207.3	192.0	191.9	189.6	203.0	11.1	5.5%
15002	0	0	1000	855.6	852.1	852.4	850.3	835.2	857.7	822.7	837.4	842.5	845.1	11.6	1.4%
15002	0	0	0	153.2	170.6	155.4	172.0	147.3	158.4	142.6	143.7	137.2	153.4	12.2	7.9%
15002	0	0	0	109.1	125.9	95.3	126.4	98.7	110.6	97.2	105.1	96.6	107.2	12.1	11.2%
15002	0	0	1000	843.1	837.6	845.4	838.4	816.7	841.5	810.5	821.1	823.2	830.8	13.0	1.6%
15002	0	0	100	164.3	181.0	154.3	182.1	152.3	167.4	147.3	153.3	149.3	161.2	13.2	8.2%
15002	0	0	1000	786.3	778.5	780.3	782.8	754.9	787.0	752.8	766.0	764.8	772.6	13.2	1.7%
15002	0	0	0	125.8	139.6	114.6	144.8	112.1	129.3	110.1	114.4	111.1	122.4	13.1	10.7%

Table B2: Figaro 823 Measurements

CALIBRATED FOR XYLENE 100,1000

H20 ppm	CH4 ppm	C4H10 ppm	C8H10 ppm	C8H10 823 #1	C8H10 823 #2	C8H10 823 #3	C8H10 823 #4	C8H10 823 #5	C8H10 823 #6	Average	Std. Dev.	% Dev.
			B	0.62	0.46	0.47	0.48	0.77	0.57	0.56	0.12	21.4%
			Ro	7.8E+04	7.9E+04	5.0E+04	8.0E+04	1.6E+05	1.0E+05	9.1E+04	3.6E+04	39.6%
15002	0	0	0	0.3	0.1	0.1	0.1	1.4	0.3	0.4	0.5	134.0%
15002	50	0	0	1.1	0.6	0.5	0.3	4.0	1.2	1.3	1.4	109.6%
15002	150	0	0	2.0	1.5	1.1	0.8	6.7	2.3	2.4	2.2	91.1%
15002	500	0	0	4.3	4.3	3.1	2.1	12.1	5.1	5.2	3.6	68.7%
15002	1500	0	0	8.3	11.3	7.7	5.1	20.4	10.6	10.6	5.3	50.0%
15002	4999	0	0	16.7	31.7	20.1	13.4	35.3	23.6	23.5	8.6	36.6%
15002	0	0	0	0.3	0.1	0.1	0.1	1.5	0.3	0.4	0.5	132.8%
15002	0	0	0	0.3	0.1	0.1	0.1	1.4	0.3	0.4	0.5	135.7%
15002	0	0	0	0.3	0.1	0.1	0.1	1.3	0.3	0.4	0.5	136.8%
15002	0	0	0	0.3	0.1	0.1	0.1	1.3	0.3	0.3	0.5	137.6%
15002	0	50	0	23.6	46.8	22.1	17.6	43.1	27.1	30.0	12.0	40.0%
15002	0	150	0	55.7	170.8	67.4	52.7	86.8	72.9	84.4	44.1	52.2%
15002	0	500	0	95.4	394.5	139.9	108.7	131.8	137.8	168.0	112.3	66.9%
15002	0	1500	0	167.5	980.8	311.0	238.7	203.9	273.1	362.5	307.1	84.7%
15002	0	4999	0	300.6	2380.9	718.7	531.4	317.3	511.3	793.4	792.9	99.9%
15002	0	0	0	0.3	0.2	0.1	0.1	1.5	0.3	0.4	0.5	126.5%
15002	0	0	0	0.2	0.1	0.1	0.0	1.2	0.2	0.3	0.4	137.5%
15002	0	0	0	0.2	0.1	0.1	0.0	1.1	0.2	0.3	0.4	141.3%
15002	0	0	0	0.2	0.1	0.1	0.0	1.1	0.2	0.3	0.4	142.3%
15002	0	0	10	12.3	4.3	9.6	5.3	20.2	12.7	10.7	5.8	53.8%
15002	0	0	30	49.1	30.6	45.0	31.6	54.3	50.1	43.5	10.0	23.0%
15002	0	0	100	100.0	100.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0%
15002	0	0	300	206.2	274.8	244.0	290.2	216.5	207.5	239.9	36.1	15.0%
15002	0	0	1000	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	0.0	0.0%
15002	0	0	0	0.6	0.2	0.2	0.2	2.3	0.7	0.7	0.8	115.6%
0	0	0	0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.1	189.9%
0	50	0	0	0.1	0.1	0.1	0.0	0.8	0.2	0.2	0.3	137.5%
0	150	0	0	0.3	0.2	0.2	0.1	1.5	0.4	0.5	0.5	113.6%
0	500	0	0	0.8	0.9	0.7	0.4	3.2	1.2	1.2	1.0	84.0%
0	1500	0	0	2.1	2.9	2.2	1.2	6.2	3.2	3.0	1.7	58.1%
0	4999	0	0	5.5	10.7	7.6	4.2	12.8	9.6	8.4	3.3	38.7%
0	0	0	0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.1	181.7%
0	0	0	0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.1	185.9%
0	0	0	0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.1	187.3%
0	0	0	0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.1	188.1%
0	0	50	0	2.0	1.4	0.9	0.6	7.1	1.9	2.3	2.4	103.2%
0	0	150	0	7.3	11.1	5.4	3.8	18.4	7.9	9.0	5.2	58.3%
0	0	500	0	24.6	70.8	27.4	19.3	43.6	-30.7	36.0	18.9	52.4%
0	0	1500	0	65.7	296.1	102.2	71.3	88.7	100.8	120.8	87.2	72.2%
0	0	4999	0	175.3	1189.5	357.4	253.3	183.7	312.3	411.9	387.5	94.1%
0	0	0	0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.1	174.9%
0	0	0	0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.1	182.3%
0	0	0	0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.1	183.3%
0	0	0	0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.1	184.3%
0	0	0	10	0.2	0.0	0.0	0.0	0.9	0.2	0.2	0.3	141.3%
0	0	0	30	2.0	0.1	0.4	0.5	4.0	1.6	1.4	1.4	100.0%
0	0	0	100	8.8	1.0	2.2	3.5	12.6	7.5	5.9	4.5	75.0%
0	0	0	300	50.5	13.2	20.5	32.5	72.2	43.9	38.8	21.5	55.4%
0	0	0	1000	495.3	280.0	338.5	346.3	535.1	631.4	437.8	136.7	31.2%
0	0	0	0	0.1	0.0	0.0	0.0	0.4	0.0	0.1	0.2	166.3%
15002	0	0	0	0.5	0.2	0.2	0.1	2.0	0.5	0.6	0.7	119.3%
15002	500	0	0	4.5	6.2	3.8	2.3	12.2	5.8	5.8	3.4	59.0%
15002	0	0	0	0.5	0.2	0.2	0.1	1.9	0.5	0.5	0.7	120.5%
15002	0	500	0	99.1	434.1	152.6	112.5	135.4	147.5	180.2	126.1	70.0%
15002	0	0	0	0.4	0.3	0.2	0.1	1.8	0.5	0.5	0.6	118.1%
15002	0	0	100	84.5	111.3	70.8	102.0	83.5	101.5	92.3	15.1	16.4%
15002	0	0	0	0.6	0.3	0.2	0.2	2.2	0.6	0.7	0.8	113.2%
15002	500	500	100	174.4	670.8	246.3	263.5	184.5	252.8	298.7	186.0	62.3%
15002	500	500	100	169.7	706.5	246.3	261.5	182.0	247.7	302.3	201.6	66.7%
15002	500	500	100	166.8	728.6	245.5	259.1	180.5	244.9	304.2	211.3	69.5%
15002	500	500	100	166.3	747.4	246.3	257.7	179.3	243.1	306.7	219.2	71.5%
15002	4999	500	100	168.0	792.7	261.9	269.0	182.4	253.5	321.2	234.9	73.1%
15002	500	500	100	163.0	768.0	245.5	254.4	177.8	242.1	308.5	228.3	74.0%
15002	500	4999	100	378.2	3220.1	891.0	744.9	362.1	659.3	1042.6	1086.7	104.2%

Table B2: Figaro 823 Measurements Con't.

H20 ppm	CH4 ppm	C4H10 ppm	C8H10 ppm	C8H10 823 #1	C8H10 823 #2	C8H10 823 #3	C8H10 823 #4	C8H10 823 #5	C8H10 823 #6	Average	Std. Dev.	% Dev.
15002	500	500	100	155.6	735.6	235.2	238.1	170.0	217.7	292.1	220.0	75.3%
15002	500	500	1000	1271.9	3090.4	1579.9	1493.5	1198.3	1688.9	1720.5	696.1	40.5%
15002	500	500	100	148.6	717.8	219.6	222.9	157.8	214.5	280.2	216.8	77.4%
15002	500	500	100	148.3	735.6	224.1	225.7	159.8	214.5	284.7	223.5	78.5%
15002	0	0	0	0.3	0.1	0.1	0.1	1.5	0.4	0.4	0.6	132.1%
15002	500	500	100	151.9	647.1	222.8	225.1	164.8	225.2	272.8	186.2	68.3%
4999	500	500	100	95.0	364.8	119.3	117.7	114.2	133.2	157.4	102.4	65.0%
1667	500	500	100	64.7	219.9	71.6	71.8	84.1	88.4	100.1	59.3	59.3%
0	500	500	100	39.5	117.4	38.7	39.6	56.0	54.1	57.6	30.3	52.7%
15002	500	500	100	163.0	815.3	252.5	256.4	175.5	245.4	318.0	247.0	77.7%
15002	4999	500	100	172.0	576.5	259.7	238.8	203.2	266.6	286.1	146.6	51.2%
15002	500	500	100	166.7	561.2	243.6	227.4	197.2	253.9	275.0	143.8	52.3%
15002	500	4999	100	402.1	1887.5	874.5	585.1	456.4	729.8	822.6	550.0	66.9%
15002	500	500	100	158.8	541.2	233.5	214.5	187.1	227.0	260.4	140.3	53.9%
15002	500	500	1000	1430.2	1822.9	1542.9	1079.0	1872.9	1966.6	1619.1	334.7	20.7%
15002	500	500	100	151.3	530.0	218.1	202.5	171.3	223.5	249.5	140.2	56.2%
15002	500	500	100	151.0	541.2	222.6	204.6	173.8	223.5	252.8	144.1	57.0%
15002	0	0	0	0.2	0.3	0.1	0.2	0.7	0.3	0.3	0.2	68.9%
15002	500	500	100	154.9	485.5	221.2	204.2	180.3	235.2	246.9	120.4	48.8%
4999	500	500	100	94.8	299.0	119.2	115.4	117.0	135.3	146.8	75.7	51.6%
1667	500	500	100	63.4	194.8	71.9	74.8	81.5	87.8	95.7	49.3	51.5%
0	500	500	100	37.9	114.5	39.0	44.3	50.4	52.4	56.4	29.1	51.5%
15002	500	500	100	166.7	590.3	250.5	229.0	194.2	257.6	281.4	155.2	55.2%
15002	0	0	0	0.4	0.2	0.2	0.1	1.9	0.5	0.5	0.7	125.8%
15002	4999	0	0	15.1	30.0	18.7	12.0	31.8	21.9	21.6	8.0	36.9%
15002	500	0	0	3.9	4.9	3.1	1.9	11.1	4.9	5.0	3.2	64.1%
15002	4999	0	0	15.3	31.9	19.2	12.1	32.0	22.1	22.1	8.4	37.8%
15002	0	0	0	0.4	0.2	0.1	0.1	1.8	0.4	0.5	0.6	128.5%
15002	0	0	0	0.4	0.1	0.1	0.1	1.7	0.4	0.5	0.6	130.5%
15002	0	0	0	0.3	0.1	0.1	0.1	1.6	0.4	0.5	0.6	131.5%
15002	0	0	0	0.3	0.1	0.1	0.1	1.6	0.4	0.5	0.6	131.5%
15002	0	4999	0	288.8	1883.1	631.5	464.0	306.0	488.8	677.0	604.3	89.3%
15002	0	500	0	83.1	370.8	120.0	83.3	113.2	112.4	147.1	110.7	75.3%
15002	0	4999	0	295.0	2351.9	660.2	469.4	300.1	498.7	762.6	790.5	103.7%
15002	0	0	0	0.4	0.3	0.1	0.1	1.7	0.4	0.5	0.6	120.5%
15002	0	0	0	0.3	0.2	0.1	0.1	1.4	0.3	0.4	0.5	128.8%
15002	0	0	0	0.3	0.1	0.1	0.1	1.4	0.3	0.4	0.5	132.2%
15002	0	0	0	0.3	0.1	0.1	0.1	1.4	0.3	0.4	0.5	133.4%
15002	0	0	1000	1243.2	2312.4	1302.9	1278.8	1154.8	1637.1	1488.2	436.1	29.3%
15002	0	0	100	62.7	96.8	54.4	73.2	63.4	71.1	70.3	14.6	20.8%
15002	0	0	1000	1257.4	2602.8	1329.4	1288.9	1169.0	1897.3	1590.8	559.8	35.2%
15002	0	0	0	2.6	1.2	0.9	0.6	5.1	2.0	2.1	1.7	80.5%

Table B3: Figaro 822 Measurements

CALIBRATED FOR XYLENE 100,1000

H20 ppm	CH4 ppm	C4H10 ppm	C8H10 ppm	C8H10 822 #1	C8H10 822 #2	C8H10 822 #3	C8H10 822 #4	C8H10 822 #5	C8H10 822 #6	C8H10 Average	C8H10 Std. Dev.	C8H10 % Dev.
			B	1.18	0.94	0.51	0.52	0.77	0.52	0.74	0.28	37.2%
			Ro	1.8E+06	5.4E+05	1.3E+05	1.2E+05	3.0E+05	2.1E+05	5.1E+05	6.4E+05	124.9%
15002	0	0	0	6.2	2.1	0.2	0.2	1.3	0.5	1.7	2.3	132.8%
15002	50	0	0	14.9	5.0	1.3	0.9	3.1	2.4	4.6	5.2	114.2%
15002	150	0	0	21.8	7.7	3.2	1.9	4.9	4.9	7.4	7.3	98.8%
15002	500	0	0	31.1	12.8	8.7	4.7	8.7	11.1	12.8	9.3	72.9%
15002	1500	0	0	43.6	19.8	20.6	10.6	14.9	23.1	22.1	11.5	51.9%
15002	4999	0	0	63.3	31.4	51.1	25.6	27.1	54.9	42.2	16.1	38.2%
15002	0	0	0	6.4	2.1	0.2	0.2	1.4	0.5	1.8	2.4	133.3%
15002	0	0	0	6.1	2.0	0.2	0.2	1.3	0.4	1.7	2.3	135.0%
15002	0	0	0	6.1	2.0	0.2	0.2	1.2	0.4	1.7	2.3	135.6%
15002	0	0	0	6.0	1.9	0.1	0.2	1.2	0.4	1.6	2.2	136.2%
15002	0	50	0	54.5	32.4	60.2	33.1	36.7	54.9	45.3	12.5	27.7%
15002	0	150	0	90.6	57.5	189.9	92.4	72.3	167.4	111.7	53.9	48.3%
15002	0	500	0	126.5	83.2	376.9	177.6	113.5	342.5	203.4	125.3	61.6%
15002	0	1500	0	177.1	124.5	776.3	367.6	185.7	754.9	397.7	296.7	74.6%
15002	0	4999	0	249.0	191.9	1611.2	757.7	311.2	1692.1	802.2	688.2	85.8%
15002	0	0	0	6.5	2.7	0.2	0.2	1.5	0.5	1.9	2.4	126.5%
15002	0	0	0	6.1	2.2	0.1	0.1	1.2	0.4	1.7	2.3	136.3%
15002	0	0	0	6.0	2.1	0.1	0.1	1.1	0.4	1.6	2.3	138.9%
15002	0	0	0	5.9	2.1	0.1	0.1	1.0	0.4	1.6	2.2	139.2%
15002	0	0	10	28.2	23.7	6.2	8.2	18.1	8.5	15.5	9.2	59.3%
15002	0	0	30	57.9	55.8	35.4	40.1	54.3	37.7	46.9	10.2	21.7%
15002	0	0	100	100.0	100.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0%
15002	0	0	300	212.3	201.6	270.5	237.7	187.5	270.6	230.0	35.4	15.4%
15002	0	0	1000	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	0.0	0.0%
15002	0	0	0	11.0	5.3	0.3	0.4	2.5	0.6	3.4	4.2	125.9%
0	0	0	0	1.7	0.6	0.0	0.0	0.2	0.0	0.4	0.7	159.3%
0	50	0	0	5.7	2.5	0.2	0.1	0.8	0.5	1.6	2.2	132.8%
0	150	0	0	9.0	4.0	0.5	0.4	1.5	1.4	2.8	3.3	118.5%
0	500	0	0	15.7	6.7	1.7	1.3	3.1	4.3	5.5	5.4	98.4%
0	1500	0	0	26.0	11.2	5.4	3.5	6.2	11.9	10.7	8.2	76.6%
0	4999	0	0	44.0	19.8	18.0	11.0	13.5	34.0	23.4	12.9	55.3%
0	0	0	0	2.1	0.8	0.0	0.0	0.2	0.0	0.5	0.8	157.4%
0	0	0	0	1.9	0.7	0.0	0.0	0.2	0.0	0.5	0.7	158.9%
0	0	0	0	1.8	0.7	0.0	0.0	0.2	0.0	0.5	0.7	159.3%
0	0	0	0	1.8	0.7	0.0	0.0	0.2	0.0	0.5	0.7	159.0%
0	0	50	0	15.3	10.1	1.9	2.2	6.6	3.2	6.6	5.3	80.8%
0	0	150	0	30.9	20.4	13.3	11.4	18.1	17.3	18.6	6.9	36.9%
0	0	500	0	63.1	39.9	72.8	46.9	43.4	87.8	59.0	18.9	32.1%
0	0	1500	0	110.8	71.8	258.3	145.5	90.4	311.4	164.7	97.7	59.3%
0	0	4999	0	198.3	140.7	865.8	454.7	196.4	1077.2	488.8	395.1	80.8%
0	0	0	0	2.8	1.0	0.0	0.0	0.3	0.1	0.7	1.1	157.7%
0	0	0	0	2.3	0.8	0.0	0.0	0.2	0.0	0.6	0.9	159.5%
0	0	0	0	2.2	0.8	0.0	0.0	0.2	0.0	0.5	0.9	159.1%
0	0	0	0	2.1	0.7	0.0	0.0	0.2	0.0	0.5	0.8	159.0%
0	0	0	10	4.7	2.8	0.0	0.1	0.8	0.1	1.4	1.9	135.3%
0	0	0	30	12.6	10.0	0.3	0.7	3.7	0.7	4.6	5.3	115.0%
0	0	0	100	30.4	27.5	1.5	4.0	12.8	3.2	13.2	12.8	96.9%
0	0	0	300	109.7	90.5	14.2	32.2	61.7	25.4	55.6	38.3	68.9%
0	0	0	1000	644.7	695.9	242.7	449.4	632.8	346.4	502.0	184.0	36.7%
0	0	0	0	4.7	1.7	0.0	0.0	0.5	0.1	1.2	1.8	158.5%
15002	0	0	0	8.2	3.5	0.2	0.3	2.0	0.7	2.5	3.1	123.7%
15002	500	0	0	34.4	17.3	8.5	4.9	9.4	13.9	14.7	10.6	71.7%
15002	0	0	0	7.8	3.2	0.2	0.3	1.9	0.6	2.3	2.9	124.6%
15002	0	500	0	133.8	95.9	398.1	182.8	114.6	366.1	215.2	132.8	61.7%
15002	0	0	0	7.8	3.2	0.2	0.3	1.9	0.6	2.3	2.9	124.6%
15002	0	0	100	97.9	100.3	85.1	107.7	105.1	102.4	99.8	8.0	8.0%
15002	0	0	0	9.0	4.0	0.3	0.3	2.2	0.7	2.8	3.4	122.3%
15002	500	500	100	172.4	152.5	551.5	325.6	188.7	535.9	321.1	182.9	57.0%
15002	500	500	100	173.1	153.1	541.1	319.2	186.6	554.6	321.3	185.0	57.6%
15002	500	500	100	173.1	153.5	534.3	317.6	184.9	573.9	322.9	188.6	58.4%
15002	500	500	100	173.1	153.9	531.8	316.9	184.6	595.8	326.0	194.0	59.5%
15002	4999	500	100	178.4	157.3	555.4	330.1	188.4	647.7	342.9	211.5	61.7%
15002	500	500	100	173.3	154.3	525.5	317.6	184.0	619.5	329.0	199.4	60.6%
15002	500	4999	100	295.8	265.4	1933.1	979.3	378.6	2437.6	1048.3	932.3	88.9%

Table B3: Figaro 822 Measurements Con't.

H20 ppm	CH4 ppm	C4H10 ppm	C8H10 ppm	C8H10 822 #1	C8H10 822 #2	C8H10 822 #3	C8H10 822 #4	C8H10 822 #5	C8H10 822 #6	C8H10 Average	C8H10 Std. Dev.	C8H10 % Dev.
15002	500	500	100	165.9	149.4	474.5	288.0	174.2	558.9	301.8	175.6	58.2%
15002	500	500	1000	1019.8	1045.8	1764.9	1622.3	1088.5	1894.5	1406.0	398.5	28.3%
15002	500	500	100	164.2	147.8	454.8	270.4	165.4	579.8	297.1	180.5	60.7%
15002	500	500	100	165.1	149.0	462.2	275.1	165.7	599.4	302.7	187.4	61.9%
15002	0	0	0	7.0	3.0	0.2	0.2	1.4	0.5	2.0	2.7	130.1%
15002	500	500	100	163.4	142.0	476.8	285.0	169.5	536.8	295.6	172.1	58.2%
4999	500	500	100	133.3	109.1	257.6	166.3	116.9	331.1	185.7	89.5	48.2%
1667	500	500	100	110.5	87.1	162.7	113.9	88.1	228.2	131.8	54.7	41.5%
0	500	500	100	87.3	66.0	93.7	72.4	62.0	149.8	88.5	32.4	36.6%
15002	500	500	100	171.8	151.6	531.8	332.2	184.9	683.7	342.7	220.3	64.3%
15002	4999	500	100	211.1	174.7	473.4	314.6	206.8	608.6	331.5	174.3	52.6%
15002	500	500	100	203.2	170.6	450.2	303.2	201.3	583.0	318.6	165.2	51.8%
15002	500	4999	100	405.2	332.5	1466.7	893.4	460.5	2191.9	958.4	738.9	77.1%
15002	500	500	100	192.1	163.9	410.4	276.0	189.1	527.8	293.2	146.2	49.9%
15002	500	500	1000	2001.8	1796.4	1350.5	1450.2	1546.9	1717.9	1644.3	241.0	14.7%
15002	500	500	100	189.7	161.7	394.9	259.8	178.1	546.9	288.5	152.9	53.0%
15002	500	500	100	191.0	163.3	400.7	264.2	178.5	564.7	293.7	159.1	54.2%
15002	0	0	0	3.2	1.3	0.3	0.3	0.8	0.6	1.1	1.1	105.0%
15002	500	500	100	188.5	154.0	412.2	273.2	183.2	507.6	286.4	143.3	50.0%
4999	500	500	100	144.8	111.3	235.9	162.9	119.7	318.1	182.1	80.1	44.0%
1667	500	500	100	113.8	84.4	155.5	113.3	86.5	222.1	129.3	52.2	40.4%
0	500	500	100	83.9	60.0	94.3	73.4	57.8	147.8	86.2	33.2	38.6%
15002	500	500	100	201.1	166.9	455.1	316.6	202.4	641.4	330.6	185.6	56.1%
15002	0	0	0	6.9	2.9	0.2	0.3	1.6	0.6	2.1	2.6	123.5%
15002	4999	0	0	61.1	33.1	44.6	22.6	24.2	51.8	39.6	15.5	39.2%
15002	500	0	0	28.3	13.9	7.5	4.2	8.1	11.6	12.3	8.5	69.6%
15002	4999	0	0	62.5	33.6	45.3	22.9	24.6	55.2	40.7	16.3	40.1%
15002	0	0	0	6.8	2.7	0.2	0.2	1.5	0.5	2.0	2.5	126.1%
15002	0	0	0	6.6	2.6	0.2	0.2	1.4	0.5	1.9	2.5	127.7%
15002	0	0	0	6.5	2.6	0.2	0.2	1.4	0.5	1.9	2.4	128.2%
15002	0	0	0	6.5	2.6	0.2	0.2	1.4	0.5	1.9	2.4	127.9%
15002	0	4999	0	244.0	188.0	1531.3	690.7	274.0	1701.2	771.5	680.4	88.2%
15002	0	500	0	111.9	76.7	298.8	140.0	95.6	291.5	169.1	99.8	59.0%
15002	0	4999	0	242.9	192.3	1507.2	702.0	284.6	1755.7	780.8	687.9	88.1%
15002	0	0	0	7.1	2.8	0.2	0.2	1.6	0.5	2.1	2.7	128.5%
15002	0	0	0	6.4	2.5	0.2	0.2	1.3	0.4	1.8	2.4	132.0%
15002	0	0	0	6.2	2.4	0.1	0.2	1.2	0.4	1.8	2.3	133.3%
15002	0	0	0	6.1	2.4	0.1	0.2	1.2	0.4	1.7	2.3	133.8%
15002	0	0	1000	913.0	962.3	1114.5	1135.4	924.4	955.7	1000.9	98.1	9.8%
15002	0	0	100	90.4	84.2	52.8	66.3	78.0	63.6	72.6	14.1	19.4%
15002	0	0	1000	943.2	978.7	1127.7	1178.0	1019.8	953.4	1033.5	97.5	9.4%
15002	0	0	0	24.2	11.6	0.8	1.0	5.9	1.3	7.5	9.2	123.6%

Table 4: Figaro 812 Measurements

	CALIBRATED FOR XYLENE 100,1000											
H20	CH4	C4H10	C8H10	C8H10 812 #13	C8H10 812 #14	C8H10 812 #15	C8H10 812 #16	C8H10 812 #17	C8H10 812 #18	Average	Std. Dev.	% Dev.
ppm	ppm	ppm	ppm									
			B	0.88	0.89	0.89	1.04	0.69	1.08	0.91	0.14	15.3%
			Ro	4.4E+05	3.7E+05	1.0E+05	2.5E+05	3.2E+04	3.4E+05	2.6E+05	1.6E+05	62.6%
15002	0	0	0	2.6	2.2	1.1	2.4	0.2	2.8	1.9	1.0	54.6%
15002	50	0	0	6.8	5.2	2.8	6.0	0.5	6.7	4.7	2.5	53.4%
15002	150	0	0	10.8	8.2	4.5	9.0	0.9	10.0	7.2	3.8	52.2%
15002	500	0	0	18.5	13.9	7.8	14.4	1.9	15.6	12.0	6.1	50.4%
15002	1500	0	0	29.9	21.9	12.4	21.7	3.6	22.9	18.7	9.3	49.5%
15002	4999	0	0	49.5	35.7	20.4	33.3	7.1	34.7	30.1	14.6	48.4%
15002	0	0	0	2.4	2.1	1.0	2.4	0.2	2.7	1.8	1.0	56.0%
15002	0	0	0	2.3	2.0	0.9	2.3	0.1	2.6	1.7	1.0	55.9%
15002	0	0	0	2.3	1.9	0.9	2.2	0.1	2.6	1.7	0.9	55.9%
15002	0	0	0	2.3	1.9	0.9	2.2	0.1	2.5	1.7	0.9	56.0%
15002	0	50	0	39.7	32.0	18.9	30.0	6.7	30.1	26.2	11.7	44.4%
15002	0	150	0	81.2	63.6	37.1	55.7	15.4	54.5	51.2	22.7	44.2%
15002	0	500	0	119.9	91.7	54.8	78.0	24.9	75.6	74.1	32.3	43.6%
15002	0	1500	0	192.1	143.3	91.4	123.0	47.4	116.3	118.9	48.7	40.9%
15002	0	4999	0	327.9	238.5	165.6	218.2	103.3	189.0	207.1	75.6	36.5%
15002	0	0	0	2.4	2.1	1.0	2.8	0.2	2.9	1.9	1.1	56.6%
15002	0	0	0	2.0	1.7	0.8	2.3	0.1	2.5	1.6	0.9	57.5%
15002	0	0	0	1.9	1.6	0.8	2.1	0.1	2.3	1.5	0.8	57.6%
15002	0	0	0	1.9	1.5	0.8	2.0	0.1	2.3	1.4	0.8	57.5%
15002	0	0	10	18.8	16.0	14.1	17.8	7.7	20.0	15.7	4.4	28.2%
15002	0	0	30	47.3	43.5	41.3	44.3	30.5	46.8	42.3	6.2	14.6%
15002	0	0	100	100.0	100.0	100.0	100.0	100.0	100.0	100.0	0.0	0.0%
15002	0	0	300	232.5	276.8	322.1	391.8	526.8	357.8	351.3	103.0	29.3%
15002	0	0	1000	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	0.0	0.0%
15002	0	0	0	4.4	4.1	2.7	6.8	0.8	6.4	4.2	2.2	53.5%
0	0	0	0	0.6	0.4	0.2	0.6	0.0	0.8	0.4	0.3	63.2%
0	50	0	0	3.0	1.8	1.1	2.5	0.2	3.1	2.0	1.2	59.1%
0	150	0	0	5.2	3.2	2.0	4.1	0.3	4.9	3.3	1.9	57.1%
0	500	0	0	9.8	6.1	3.7	7.1	0.7	8.3	5.9	3.3	55.4%
0	1500	0	0	17.4	11.0	6.4	11.5	1.6	13.1	10.2	5.5	54.1%
0	4999	0	0	32.4	20.9	11.8	19.3	3.6	21.5	18.2	9.7	53.4%
0	0	0	0	0.6	0.4	0.2	0.7	0.0	0.8	0.5	0.3	62.7%
0	0	0	0	0.6	0.4	0.2	0.6	0.0	0.8	0.4	0.3	63.2%
0	0	0	0	0.6	0.4	0.2	0.6	0.0	0.8	0.4	0.3	63.2%
0	0	0	0	0.6	0.4	0.2	0.6	0.0	0.8	0.4	0.3	63.1%
0	0	50	0	11.5	8.6	5.4	9.5	1.4	10.2	7.7	3.7	48.2%
0	0	150	0	26.0	19.1	11.5	18.6	3.6	19.5	16.4	7.8	47.3%
0	0	500	0	55.8	39.7	23.1	34.3	8.7	35.1	32.8	15.8	48.4%
0	0	1500	0	110.0	76.7	44.7	60.5	20.4	60.5	62.1	30.2	48.6%
0	0	4999	0	237.2	162.4	102.4	124.5	57.6	121.8	134.3	60.9	45.3%
0	0	0	0	0.8	0.6	0.3	0.9	0.0	1.2	0.6	0.4	64.3%
0	0	0	0	0.7	0.5	0.3	0.7	0.0	0.9	0.5	0.3	64.4%
0	0	0	0	0.7	0.4	0.2	0.7	0.0	0.9	0.5	0.3	64.6%
0	0	0	0	0.7	0.4	0.2	0.7	0.0	0.8	0.5	0.3	64.5%
0	0	0	10	2.8	2.3	1.7	2.6	0.5	3.5	2.2	1.0	46.3%
0	0	0	30	9.3	8.9	7.9	9.7	4.1	12.1	8.7	2.7	30.6%
0	0	0	100	25.8	30.9	26.5	32.1	21.6	33.5	28.4	4.5	16.0%
0	0	0	300	86.4	139.7	113.5	152.6	120.1	148.7	126.8	25.2	19.8%
0	0	0	1000	533.1	506.2	395.2	432.9	227.4	487.0	430.3	111.3	25.9%
0	0	0	0	1.4	1.2	0.8	2.6	0.2	2.7	1.5	1.0	67.6%
15002	0	0	0	2.6	2.1	1.2	2.4	0.2	2.7	1.9	1.0	52.2%
15002	500	0	0	20.9	14.9	8.9	15.9	2.3	17.2	13.4	6.7	50.0%
15002	0	0	0	3.2	2.5	1.4	3.0	0.3	3.3	2.3	1.2	53.2%
15002	0	500	0	139.1	103.4	64.8	87.9	31.2	85.0	85.2	36.3	42.5%
15002	0	0	0	2.8	2.3	1.2	2.8	0.2	3.1	2.1	1.1	54.7%
15002	0	0	100	127.9	122.3	121.4	117.9	123.9	116.6	121.7	4.1	3.4%
15002	0	0	0	3.5	3.0	1.7	4.0	0.4	4.2	2.8	1.5	52.1%
15002	500	500	100	213.6	178.3	159.6	184.8	149.4	167.7	175.6	22.5	12.8%
15002	500	500	100	211.2	177.8	158.5	187.8	148.7	168.6	175.4	22.3	12.7%
15002	500	500	100	208.9	176.3	155.6	187.2	145.8	168.2	173.7	22.7	13.0%
15002	500	500	100	207.9	174.7	153.4	185.5	142.3	166.4	171.7	23.4	13.6%
15002	4999	500	100	216.4	179.8	156.2	189.0	144.4	169.9	175.9	25.5	14.5%
15002	500	500	100	205.6	173.0	149.2	182.6	136.4	163.5	168.4	24.6	14.6%
15002	500	4999	100	415.4	317.0	253.8	309.6	224.6	253.8	297.4	67.5	22.7%

Table 4: Figaro 812 Measurements Con't

H20 ppm	CH4 ppm	C4H10 ppm	C8H10 ppm	C8H10 812 #13	C8H10 812 #14	C8H10 812 #15	C8H10 812 #16	C8H10 812 #17	C8H10 812 #18	Average	Std. Dev.	% Dev.
15002	500	500	100	193.3	161.0	141.4	175.1	130.2	157.1	159.7	22.7	14.2%
15002	500	500	1000	1061.5	1052.7	1048.1	1045.9	1064.6	1045.8	1053.1	8.2	0.8%
15002	500	500	100	194.4	162.4	152.4	202.3	141.7	182.7	172.7	24.2	14.0%
15002	500	500	100	191.8	158.7	138.5	173.5	125.5	158.7	157.8	23.7	15.0%
15002	0	0	0	2.0	1.6	0.9	2.2	0.2	2.6	1.6	0.9	56.9%
15002	500	500	100	182.5	151.8	127.9	156.7	111.2	143.2	145.6	24.6	16.9%
4999	500	500	100	132.8	111.4	85.5	108.8	68.8	102.5	101.6	22.2	21.8%
1667	500	500	100	104.7	87.8	63.2	81.8	47.1	79.2	77.3	20.0	25.8%
0	500	500	100	79.5	65.6	43.9	58.7	27.3	59.0	55.6	18.1	32.5%
15002	500	500	100	196.6	161.7	132.0	162.9	115.1	147.0	152.5	28.2	18.5%
15002	0	0	0	2.1	1.7	0.8	2.1	0.1	2.3	1.5	0.9	56.7%
15002	4999	0	0	46.6	34.8	20.0	30.5	6.2	32.4	28.4	13.8	48.6%
15002	500	0	0	16.8	13.0	7.1	12.8	1.5	13.6	10.8	5.5	51.3%
15002	4999	0	0	47.0	35.3	19.8	30.8	6.3	32.2	28.6	14.0	48.9%
15002	0	0	0	2.0	1.6	0.8	2.1	0.1	2.3	1.5	0.9	58.0%
15002	0	0	0	1.9	1.6	0.7	2.0	0.1	2.2	1.4	0.8	57.7%
15002	0	0	0	1.9	1.5	0.7	1.9	0.1	2.2	1.4	0.8	57.7%
15002	0	0	0	1.9	1.5	0.7	1.9	0.1	2.1	1.4	0.8	57.7%
15002	0	4999	0	309.4	229.9	163.7	204.4	93.9	178.7	196.7	71.9	36.6%
15002	0	500	0	103.3	80.1	50.7	71.6	20.9	68.3	65.8	27.9	42.4%
15002	0	4999	0	308.8	231.6	160.8	204.4	94.6	177.3	196.2	72.0	36.7%
15002	0	0	0	2.0	1.7	0.8	2.5	0.1	2.5	1.6	1.0	59.0%
15002	0	0	0	1.7	1.4	0.7	2.0	0.1	2.2	1.4	0.8	59.5%
15002	0	0	0	1.7	1.3	0.7	1.9	0.1	2.1	1.3	0.8	59.3%
15002	0	0	0	1.6	1.3	0.6	1.8	0.1	2.0	1.2	0.7	59.3%
15002	0	0	1000	950.9	990.6	1063.4	1045.9	1064.6	987.6	1017.2	47.3	4.7%
15002	0	0	100	96.0	93.0	106.7	144.1	100.8	115.7	109.4	18.8	17.2%
15002	0	0	1000	962.0	985.9	1030.8	1031.7	1031.5	1000.0	1007.0	29.3	2.9%
15002	0	0	0	11.5	10.7	11.9	30.0	4.3	25.1	15.6	9.8	63.0%

Table 5: Figaro 813 Measurements

CALIBRATED FOR Methane 500/5000

H20 ppm	CH4 ppm	C4H10 ppm	C8H10 ppm	CH4 813 #19	CH4 813 #20	CH4 813 #21	CH4 813 #22	CH4 813 #23	CH4 813 #24	Average	Std. Dev.	% Dev.
			B	0.46	0.47	0.43	0.50	0.52	0.47	0.47	0.03	6.7%
			Ro	1.6E+05	1.9E+05	1.6E+05	1.5E+05	2.1E+05	1.7E+05	1.7E+05	2.1E+04	12.3%
15002	0	0	0	62.4	88.6	69.2	90.9	67.4	101.7	80.0	15.8	19.7%
15002	50	0	0	101.2	134.1	112.5	133.4	104.4	145.3	121.8	18.2	14.9%
15002	150	0	0	183.5	220.8	210.0	216.1	184.2	235.4	208.3	20.7	10.0%
15002	500	0	0	500.0	500.0	500.0	500.0	500.0	500.0	500.0	0.0	0.0%
15002	1500	0	0	1388.7	1323.1	1280.3	1346.5	1359.4	1284.4	1330.4	42.8	3.2%
15002	4999	0	0	5000.0	5000.0	5000.0	5000.0	5000.0	5000.0	5000.0	0.0	0.0%
15002	0	0	0	60.6	85.0	62.3	90.1	59.7	91.7	74.9	15.5	20.7%
15002	0	0	0	60.1	82.5	62.3	88.9	59.7	90.5	74.0	14.8	20.0%
15002	0	0	0	60.0	81.4	62.3	88.2	59.7	89.8	73.6	14.4	19.6%
15002	0	0	0	59.7	80.6	62.2	88.1	59.9	89.3	73.3	14.2	19.4%
15002	0	50	0	113.8	156.2	122.9	135.2	121.5	143.7	132.2	15.9	12.0%
15002	0	150	0	257.5	299.3	240.4	228.0	280.6	256.9	260.4	26.0	10.0%
15002	0	500	0	469.4	492.0	374.7	322.3	513.6	403.7	429.3	74.5	17.3%
15002	0	1500	0	1196.9	1172.7	931.3	636.5	1353.9	904.1	1032.6	258.3	25.0%
15002	0	4999	0	5135.6	4542.2	4416.6	2016.7	5585.7	3671.9	4228.1	1264.9	29.9%
15002	0	0	0	57.4	71.0	50.6	82.5	59.1	80.1	66.8	13.0	19.5%
15002	0	0	0	57.3	70.0	49.2	84.2	58.6	78.8	66.3	13.6	20.4%
15002	0	0	0	57.3	69.2	48.1	85.5	58.5	78.1	66.1	14.1	21.3%
15002	0	0	0	57.5	69.1	47.3	85.9	58.5	77.6	66.0	14.3	21.6%
15002	0	0	10	66.4	79.9	53.9	98.1	71.8	95.7	77.6	17.2	22.1%
15002	0	0	30	78.5	93.9	62.8	113.5	90.3	116.2	92.5	20.4	22.1%
15002	0	0	100	102.6	121.8	82.5	140.0	130.6	151.5	121.5	25.3	20.8%
15002	0	0	300	165.3	188.3	132.9	188.0	202.8	214.6	182.0	29.2	16.0%
15002	0	0	1000	321.6	370.3	297.3	316.8	426.5	445.7	363.0	61.8	17.0%
15002	0	0	0	58.3	69.2	47.5	87.1	62.0	81.6	67.6	14.8	21.9%
0	0	0	0	4.3	6.3	4.1	6.8	5.4	7.2	5.7	1.3	22.8%
0	50	0	0	13.1	17.3	16.5	14.0	18.6	20.5	16.6	2.8	16.9%
0	150	0	0	37.9	47.1	54.4	31.8	53.4	57.9	47.1	10.3	21.8%
0	500	0	0	170.5	186.6	251.7	128.7	210.5	249.4	199.6	47.6	23.9%
0	1500	0	0	723.8	667.0	850.6	548.4	765.8	831.4	731.2	112.3	15.4%
0	4999	0	0	3858.2	3358.5	4160.8	3333.5	3522.7	3711.1	3657.5	319.1	8.7%
0	0	0	0	3.7	5.5	3.7	5.9	4.5	6.1	4.9	1.1	21.7%
0	0	0	0	3.9	5.7	4.0	6.2	4.8	6.5	5.2	1.1	21.5%
0	0	0	0	4.1	6.0	4.1	6.3	5.0	6.7	5.4	1.1	21.2%
0	0	0	0	4.3	6.2	4.3	6.5	5.2	6.9	5.6	1.1	20.3%
0	0	50	0	10.6	15.6	11.8	13.2	15.4	18.0	14.1	2.7	19.4%
0	0	150	0	27.8	41.4	35.1	28.9	42.1	47.2	37.1	7.8	21.0%
0	0	500	0	99.2	142.5	135.3	81.7	138.0	152.9	124.9	27.9	22.4%
0	0	1500	0	416.7	436.7	489.9	257.1	523.2	-487.6	435.2	95.5	21.9%
0	0	4999	0	2995.1	2609.2	2920.8	1220.3	3224.7	2291.0	2543.5	725.1	28.5%
0	0	0	0	3.8	5.6	3.7	5.9	4.7	6.1	5.0	1.1	21.2%
0	0	0	0	3.9	5.8	4.0	6.1	4.9	6.5	5.2	1.1	21.5%
0	0	0	0	4.1	6.0	4.1	6.3	5.1	6.8	5.4	1.2	21.3%
0	0	0	0	4.3	6.3	4.2	6.5	5.2	7.0	5.6	1.2	21.2%
0	0	0	10	5.3	7.5	5.3	8.5	8.1	12.1	7.8	2.5	32.6%
0	0	0	30	7.2	9.8	7.0	11.8	12.7	20.8	11.5	5.1	44.0%
0	0	0	100	12.8	16.8	12.8	20.5	25.8	44.2	22.2	11.9	53.6%
0	0	0	300	36.6	47.2	37.1	49.3	62.5	107.5	56.7	26.6	47.0%
0	0	0	1000	128.4	170.1	158.5	150.5	204.3	338.5	191.7	76.1	39.7%
0	0	0	0	4.6	6.4	4.5	7.0	5.8	8.1	6.1	1.4	23.2%
15002	0	0	0	41.2	58.4	45.0	61.7	45.7	72.9	54.2	12.2	22.6%
15002	500	0	0	635.7	682.8	697.6	750.1	631.2	781.1	696.4	60.3	8.7%
15002	0	0	0	73.7	104.3	82.5	111.6	79.5	127.2	96.5	21.1	21.9%
15002	0	500	0	613.4	672.9	606.6	444.2	677.1	608.3	603.7	84.5	14.0%
15002	0	0	0	71.7	95.7	76.2	106.1	75.7	116.4	90.3	18.5	20.5%
15002	0	0	100	126.9	166.8	135.5	175.9	168.7	236.3	168.4	38.7	23.0%
15002	0	0	0	70.5	92.8	75.4	104.7	73.5	110.5	87.9	17.2	19.6%
15002	500	500	100	1294.7	1197.9	1139.1	1045.4	1399.2	1237.3	1218.9	122.9	10.1%
15002	500	500	100	1185.5	1146.5	999.2	1006.1	1339.1	1178.5	1142.5	127.2	11.1%
15002	500	500	100	1110.3	1120.8	928.4	977.2	1312.4	1144.2	1098.9	135.7	12.4%
15002	500	500	100	1038.7	1091.3	854.6	950.9	1296.6	1098.3	1055.1	150.2	14.2%
15002	4999	500	100	6197.1	6151.8	5768.0	6749.8	6844.7	6753.5	6410.8	435.1	6.8%
15002	500	500	100	954.8	1054.1	807.0	893.3	1223.5	1053.8	997.7	145.9	14.6%
15002	500	4999	100	6570.9	6411.7	5478.7	3536.2	7771.8	5726.5	6082.6	1411.9	23.2%

Table 5: Figaro 813 Measurements Con't												
				CH4	CH4	CH4	CH4	CH4	CH4			
H20	CH4	C4H10	C8H10	813 #19	813 #20	813 #21	813 #22	813 #23	813 #24	Average	Std. Dev.	% Dev.
ppm	ppm	ppm	ppm									
15002	500	500	100	820.4	886.8	707.0	787.6	1079.4	899.3	863.4	126.9	14.7%
15002	500	500	1000	1487.9	1639.7	1584.7	1340.0	2111.3	1888.7	1675.4	280.2	16.7%
15002	500	500	100	839.0	927.0	755.2	869.7	1142.6	946.4	913.3	131.4	14.4%
15002	500	500	100	813.9	914.7	735.6	860.3	1133.1	904.1	893.6	134.4	15.0%
15002	0	0	0	61.9	74.7	46.4	94.2	64.3	84.6	71.0	17.2	24.2%
15002	500	500	100	958.4	879.6	684.8	824.7	1145.0	833.6	887.7	154.5	17.4%
4999	500	500	100	508.4	478.5	401.7	407.4	659.9	450.8	484.5	95.2	19.6%
1667	500	500	100	357.9	338.9	302.5	272.9	492.6	317.8	347.1	77.1	22.2%
0	500	500	100	274.9	264.5	251.1	199.2	398.0	243.5	271.9	67.1	24.7%
15002	500	500	100	886.3	909.8	776.4	853.9	1214.7	797.2	906.4	159.4	17.6%
15002	0	0	0	58.0	90.9	64.5	92.5	66.0	111.6	80.6	21.0	26.0%
15002	4999	0	0	5298.7	6348.7	6614.5	7565.0	4800.9	7011.3	6273.2	1044.3	16.6%
15002	500	0	0	407.4	539.8	408.1	617.4	431.9	529.6	489.0	86.2	17.6%
15002	4999	0	0	4238.5	5639.2	4957.0	6209.5	4506.5	5954.4	5250.8	803.7	15.3%
15002	0	0	0	56.4	89.1	59.9	90.5	64.4	97.7	76.3	18.1	23.7%
15002	0	0	0	56.2	87.9	59.2	90.3	63.8	96.1	75.6	17.7	23.5%
15002	0	0	0	55.9	86.9	59.0	90.1	63.5	94.9	75.0	17.4	23.2%
15002	0	0	0	56.0	86.5	59.0	89.6	63.3	94.4	74.8	17.2	23.0%
15002	0	4999	0	5352.5	5245.8	5343.7	2290.2	5520.1	4130.7	4647.2	1259.0	27.1%
15002	0	500	0	332.4	422.9	301.8	283.3	379.1	337.9	342.9	51.1	14.9%
15002	0	4999	0	4616.2	4636.9	4534.4	2064.6	5055.9	3703.9	4102.0	1091.5	26.6%
15002	0	0	0	53.8	79.1	49.2	84.2	63.6	85.2	69.2	15.8	22.8%
15002	0	0	0	53.7	78.2	47.2	84.6	62.9	84.5	68.5	16.2	23.6%
15002	0	0	0	53.7	78.0	46.0	84.7	62.7	84.5	68.3	16.5	24.2%
15002	0	0	0	53.8	77.6	45.2	84.6	62.1	84.2	67.9	16.7	24.5%
15002	0	0	1000	331.3	427.2	323.8	349.3	455.0	519.0	400.9	78.8	19.6%
15002	0	0	100	91.4	123.6	80.4	130.5	136.8	156.9	119.9	28.8	24.0%
15002	0	0	1000	323.8	415.7	330.7	341.6	467.1	531.2	401.7	84.8	21.1%
15002	0	0	0	54.7	77.0	51.0	87.1	67.4	90.5	71.3	16.5	23.1%

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