General information on the Capteur NGL07 Carbon Monoxide sensors

Principle of Operation

The Capteur 'G' series sensor is a Mixed Metal Oxide semiconductor based on Chromium Titanium Oxide. When heated to a high temperature the material behaves towards reducing gases as a p-type semiconductor and increases in resistance in the presence of a reducing gas, such as Carbon Monoxide. This contrasts with Tin Dioxide, which is an n-type material that decreases in resistance in the presence of a reducing gas. See table 1

Material type	Oxidising environment	Reducing Environment
n-type	Resistance rise	Resistance fall
p-type	Resistance fall	Resistance rise

Table 1. Classification of sensor Materials

Electronic theory of Operation

One of the important properties of a semiconductor is the concentration of charge carriers. As semiconductors in general contain relatively few free charge carriers this facilitates control of their behaviour and concentration by external means. In a clean semiconductor, negative free electrons and positive free holes are present in equal numbers. These electrons and holes are created by the thermal excitation of valence electrons from the valence states, in the crystal, to the conduction band leaving behind positive holes in the valence band. (See Fig1.)

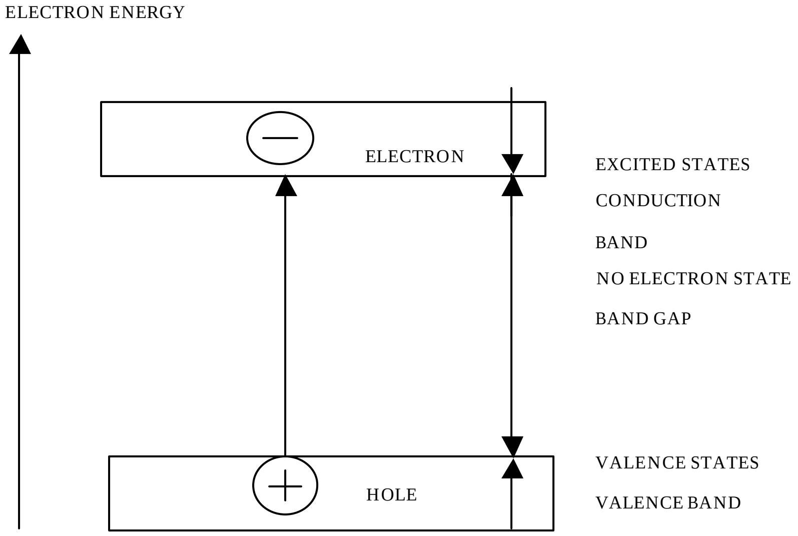


Figure1

Band gap explanation of semiconduction in solids

This is true for a so-called ‘intrinsic’ semiconductor, for a pure oxide system, and is equally true for Silicon or Germanium. For most commercial applications of semiconductor materials it is necessary to add a dopant, which supplies an excess of holes or electrons that form the majority current carrier, i.e. p or n type semiconductors. For the Chrome Titanium oxide system, Chrome oxide is the intrinsic semiconductor, which, with a valency state of 3^+, when doped with Titanium, of valency 4^+, now becomes a p-type semiconductor. The Titanium requires an extra electron, which it takes from the Chrome d-band leaving a hole. The electron it takes is trapped by an oxygen atom forming TiO_2.Therefore Oxygen adsorbed at the gas–solid interface removes electrons from the surface region of the solid to form a surface oxygen ion; the oxygen can be thought of as a surface trap for electrons from the Chrome oxide d-band (see Fig 2).

Therefore the adsorbed oxygen gives rise to an increase in the hole concentration, and it follows that any decrease in the surface coverage of Oxygen ions by reacting with, for example, CO to form CO_2 would release electrons back into the lower band and decrease the hole concentration and hence lead to an increase in the resistance of the semiconductor material.

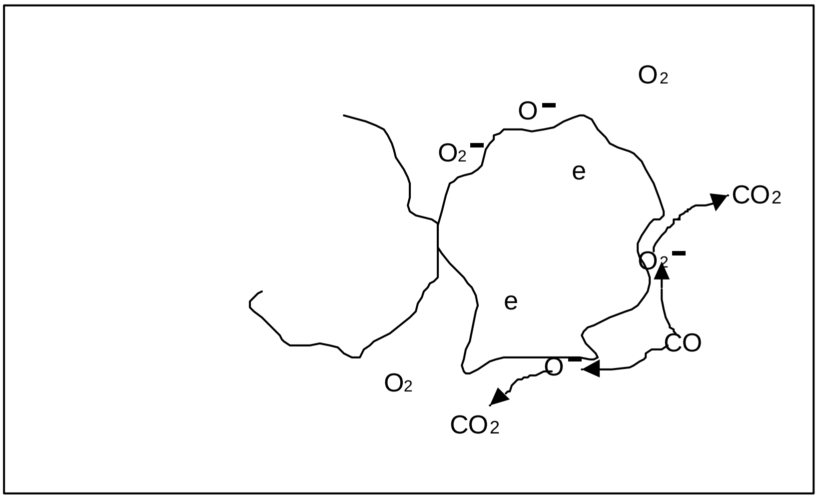


Figure 2

The correlation between the sensor resistance and the concentration of the reducing gas can be given in the following general function:

$$Rg=Ro\ (1+k\sqrt{C})$$

where:

Rg=electrical resistance of sensor material in reducing gas
Ro=electrical resistance of sensor material at zero PPM
K=constant for particular sensor in specific reducing gas
C=gas concentration in PPM

Sensor Characteristics

Sensitivity to gas

With reference to the response function given in the first section the correlation of the sensor resistance and gas concentration may be plotted as a linear function against the Square Root of the gas concentration. Figure 3 shows a typical example of the sensitivity of the NGL07 CO sensor to Carbon Monoxide.

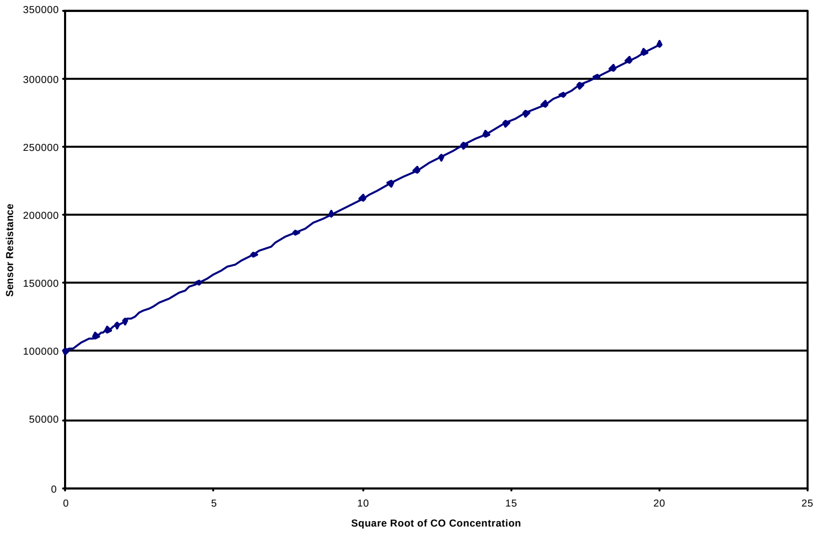


Figure 3

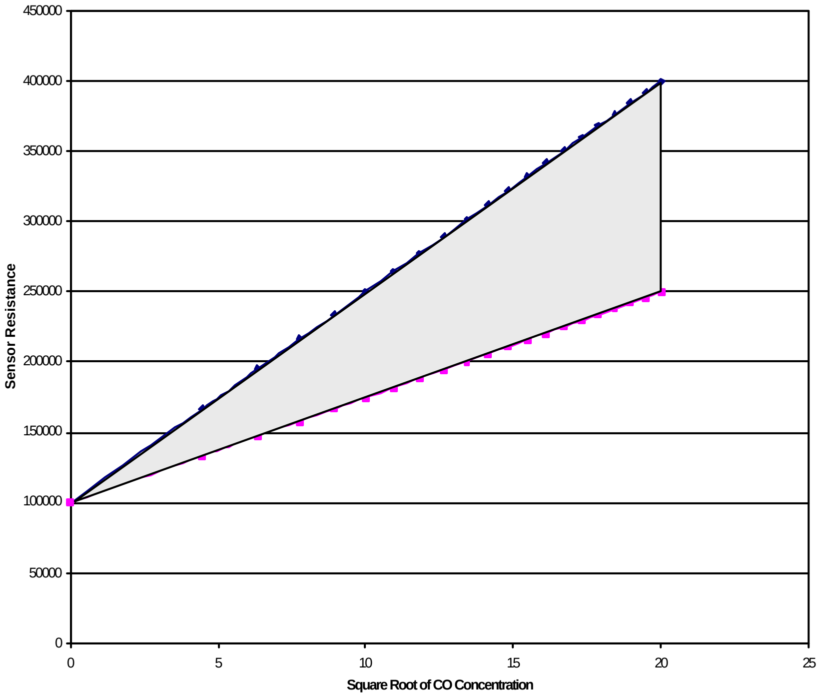
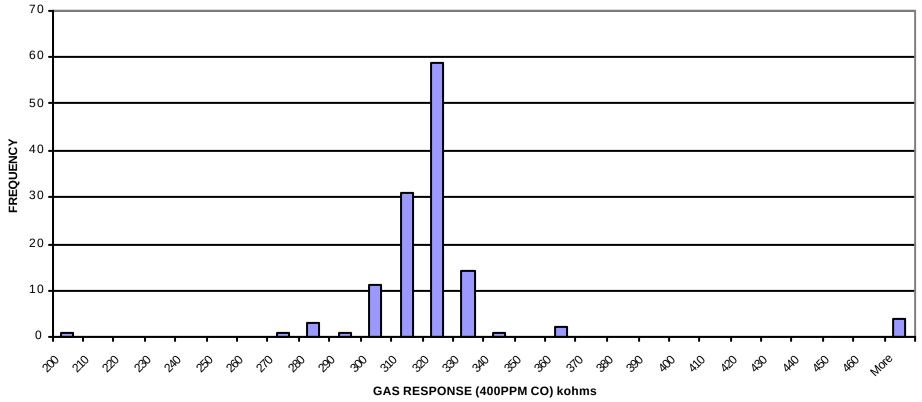
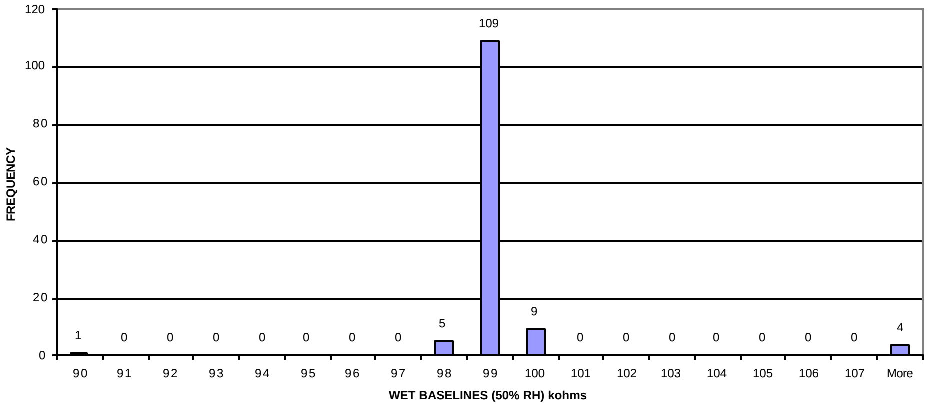


Figure 4

Figure 4 shows the sensitivity range of the Capteur NGL07 Carbon Monoxide sensor. All sensors will operate within the shaded area shown on the graph. Each sensor is subjected to a gas test prior to despatch. Statistical analyses of various sensor parameters are collected. The following four charts show typical results on a random set of 128 sensors during final testing.

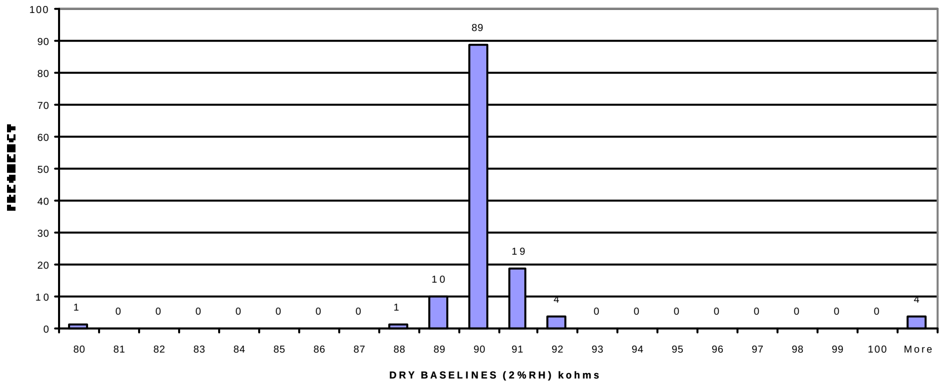

DISTRIBUTION OF GAS RESPONSES TO 400 PPM CO FOR NGL07 SENSORS G212 (G091299C)

All NGL07 production sensors are subjected to a CO exposure of 400ppm the above chart shows the distribution of response to the gas.


DISTRIBUTION OF WET BASELINES (50% RH) FOR NGL07 SENSORS G212 (G091299C)

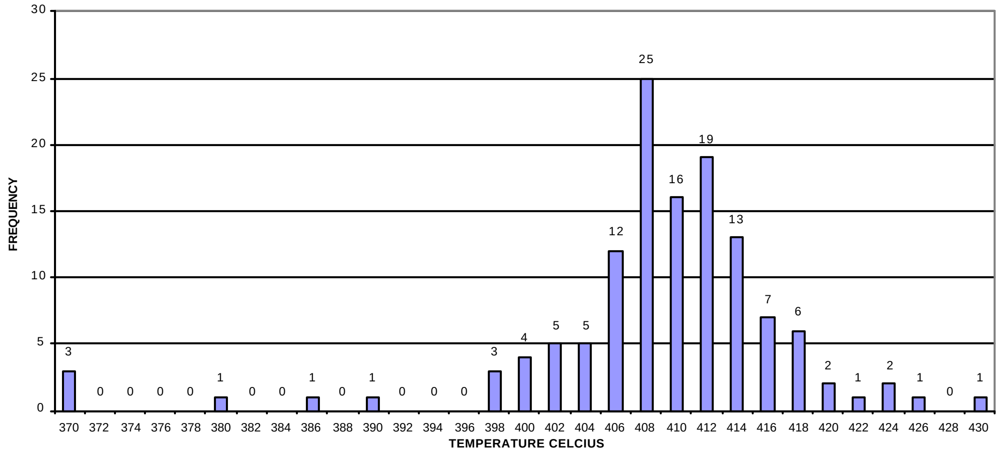
The very tight distribution on the baseline of 100K ohms, when set in 50% RH at 22°C, is evidenced in the above graph.

DISTRIBUTION OF DRY BASELINES (2% RH) FOR NGL07 SENSORS
G212 (G091299C)



The sensors are tested in air at 2% RH as a check on their response to changes in humidity. Th graph above shows the results.

DISTRIBUTION OF TEMPERATURES FOR NGL07 SENSORS
G212 (G091299C)



As a further check on sensor performance the operating temperatures of the sensors are calculated and collated for adherence to pass/ fail criteria, again the tight spread can be seen in the graph shown here.

Sensor Response

Capteur monitors the NGL07 sensors for long-term stability in air with a daily exposure to 400 ppm of Carbon Monoxide. The sensors are continuously powered in a test chamber while clean air is allowed to flow through the apparatus. The gas exposure level is achieved by injecting a known volume of 100% CO into the chamber. Figure 5 demonstrates a typical rate of response when exposed to a concentration of 400-ppm Carbon Monoxide. The response time to 90% of the sensitivity is of the order of 2.5 minutes and the time to the maximum sensitivity is shown to be 4 minutes. The speed of return to normal is a function of the rate at which the gas is purged from the chamber. The equivalent resistance value for 70ppm is shown as the dotted line on the graph, it can be seen that the sensor rapidly drops below the alarm level.

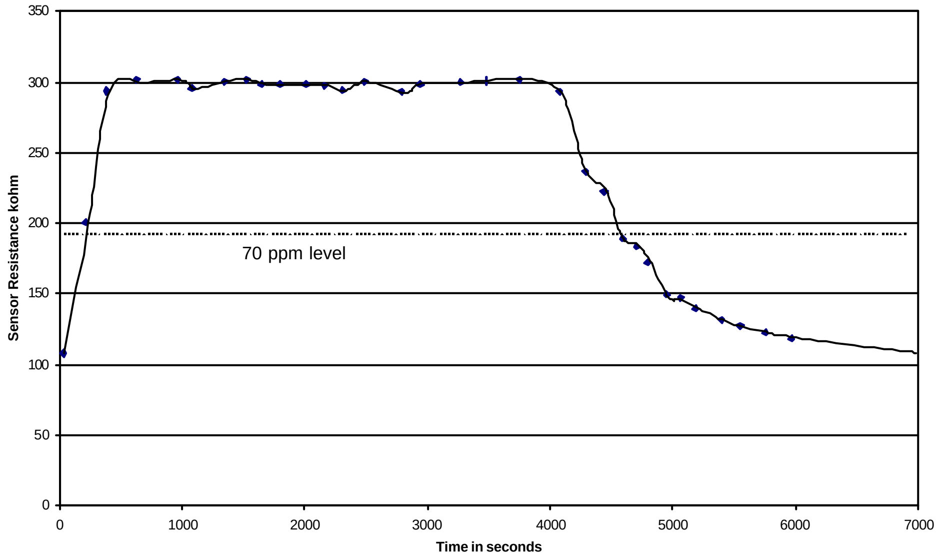


Figure 5 (above)

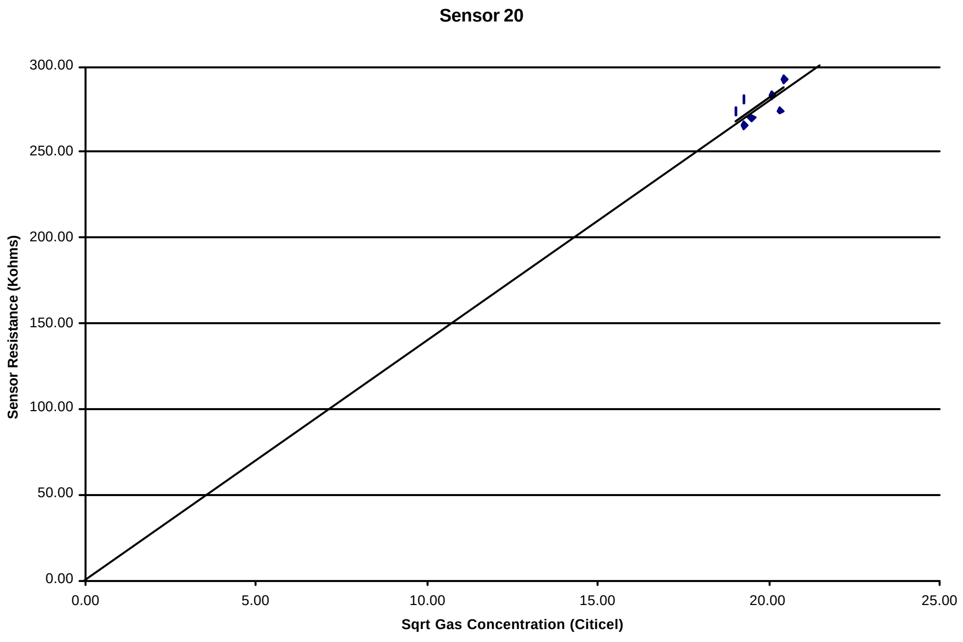

Sensor 20

Figure 6

The continuing monitoring of the sensors also provides evidence of the repeatable accuracy of the NGL07 sensor when compared to a Citicel electrochemical CO sensor. Figure 6 (over-leaf) shows the typical degree of accuracy obtained.

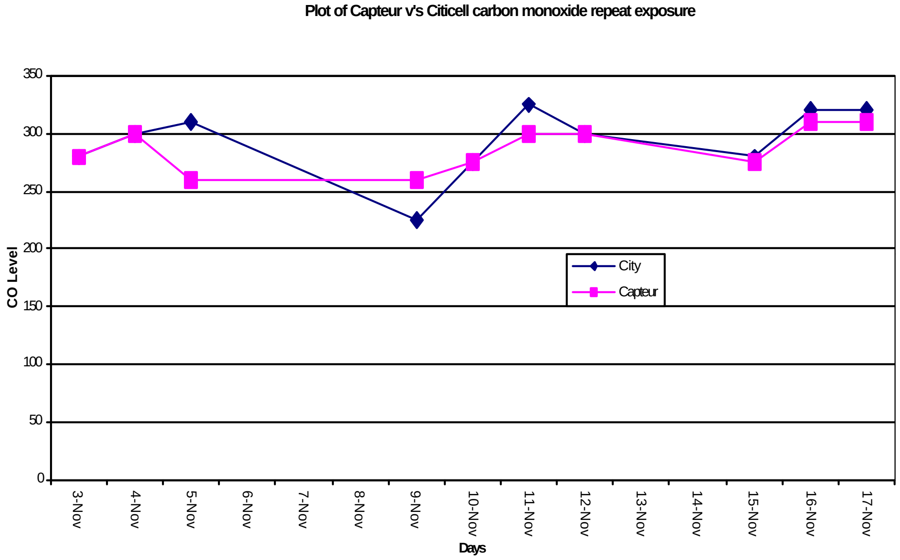


Figure 7

When plotted against the number of exposures it can be seen in Figure 7 that there is no evidence of sensor drift after repeated exposures to 400ppm of CO.

Dependency on Relative Humidity

Figure 8 illustrates the effects of RH% change at constant temperature and shows a shift of approximately 10% in baseline, though this is the extreme, and 5% shift is more typical. A 5% change is less than the equivalent of 0.5 ppm of CO.

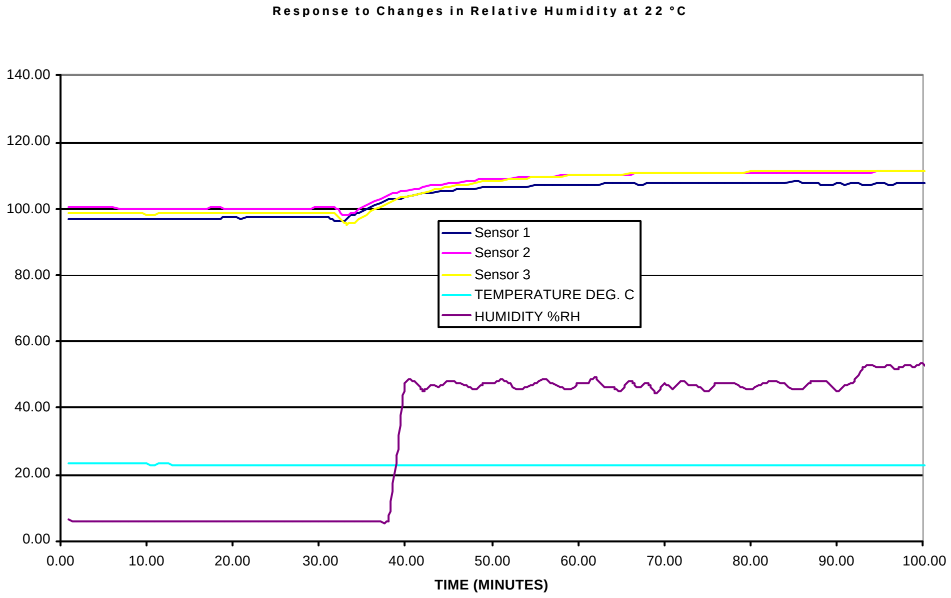


Figure 8
Effects of Ambient Temperature

Figure 9 illustrates the effect of ambient temperature changes of the gas environment on the NGL07 sensor and shows the sensor to be relatively unaffected significant temperature excursions.

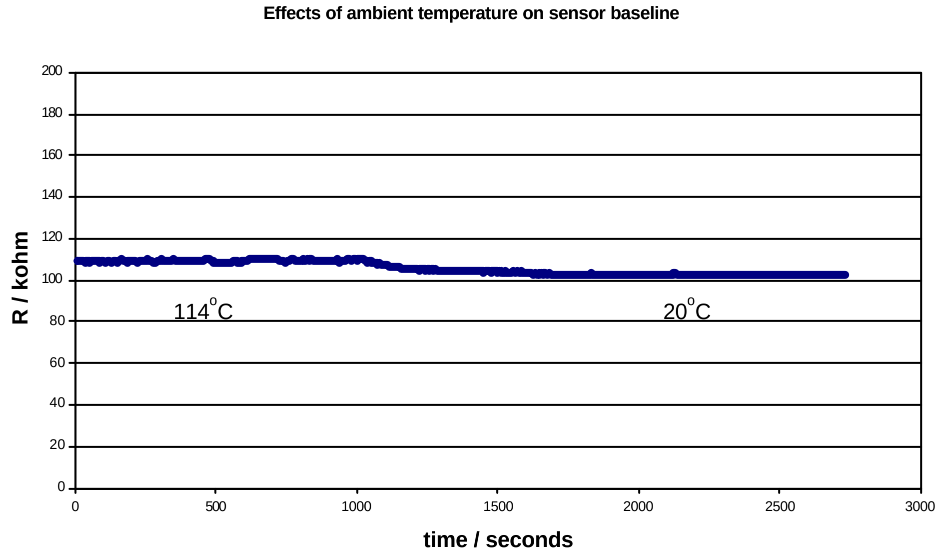


Figure 9

Utilisation of NGL07 Sensor

The NGL07 sensor has been specifically designed to pass both the UL2034 and the Cenelec prEN 50291:1999 standards for Carbon Monoxide Detectors. Figure 10 shows the lack of response to the UL gas selectivity test. Each gas was applied for two hours with a five-minute air step in between each exposure.

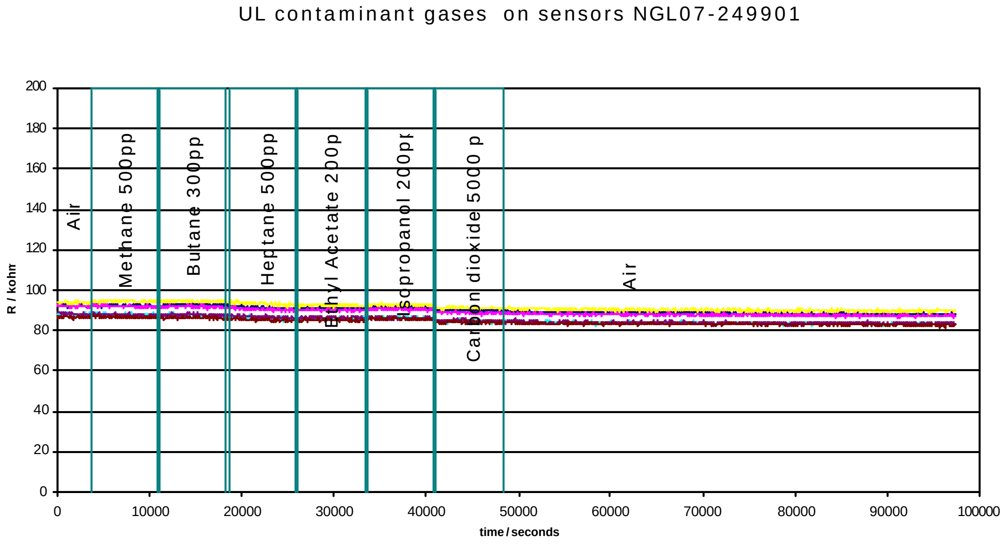


Figure 10

One of the tests for UL2034 is an exposure to 15 ppm of Carbon Monoxide for twelve months. The following graph, figure 11, shows twelve sensors after nine months into the test. The equivalent sensor resistance to 70 ppm, the lower alarm limit, is shown on the graph for reference.

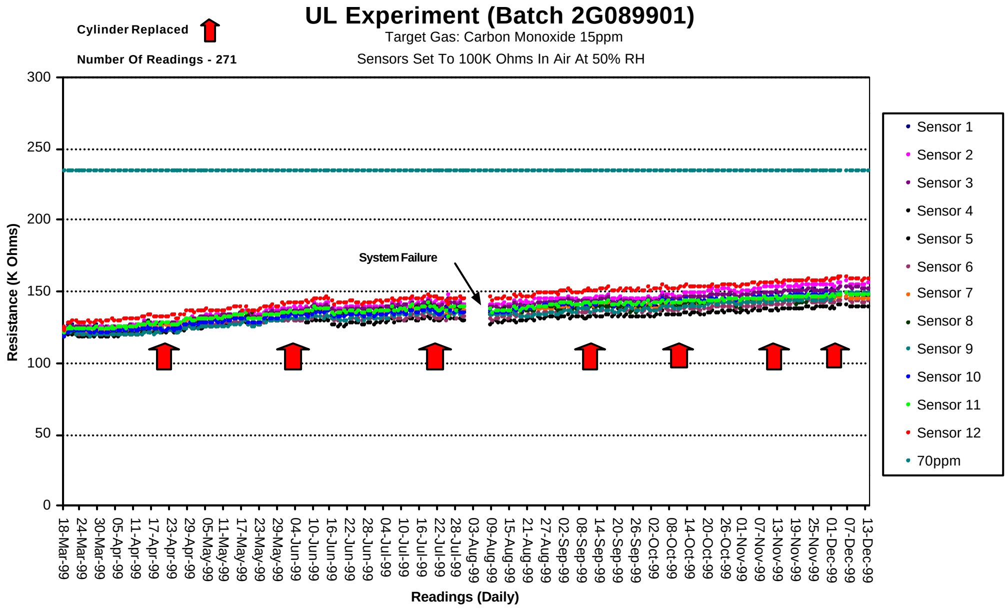


Figure 11

Integration of the NGL07 sensor into a CO Detector

Introduction

All sensors are supplied with clean activated carbon filters packed in trays of 80. Each sensor has an adhesive disc on the open end of the filter. When the disc is removed the filters will begin to absorb contamination (VOCs) from the surrounding environment. The degree of contamination will depend on the local air quality and the length of time that the sensors are left powered down. The new Advanced Filter Technology (AFT$^{©}$) developed at Capteur now allows the sensors to be calibrated within 1 hour of being powered up. This also applies to detectors when first powered up using the Capteur CO sensor.
After calibration you will have a well functioning Carbon Monoxide detector.

Sensor Characterisation & Calibration

An important point to stress is that, although each sensor is supplied with individual characterisation data, it is the detector that must be calibrated. The sensor characterisation data is proof that each sensor performs within strict criteria before it is released to the detector manufacturer. The actual calibration should be with the finished electronics and case.

Calibration Procedures & Requirements

The manufacturer of the detector units should be aware that the following 'disciplines' are required:
Clean air from an oil free compressor or bottled air, not nitrogen, dried to 50% RH at 21°C should be available for base-line setting and gas calibration.
A gas tight enclosure is necessary. Silicones should be avoided if possible, but if silicone sealants are used they must be in thin cross sectional areas and allowed to cure thoroughly, as volatile organo silicones will deteriorate sensor performance.
It is envisage that good manufacturing procedures are observed in the test and calibration area, and relevant Health and Safety regulations are adhered to. Typically this will ensure a clean environment in which to set up detectors.
A facility to inject a known volume of carbon monoxide to achieve a required concentration of the gas, or a facility to switch between air and gas at a known concentration value and flow rate. The time to fully exchange the air/gas volumes for the latter will need to be quantified.
Sensors must be soldered to the boards by hand in an environment as above.

Clean air supply

There are two approaches for obtaining a clean air supply, use of bottled air or generate clean air from ambient air.

Bottled air. Zero grade air available from commercial gas and gas mixture suppliers should have the following maximum impurities: less than 0.5 PPM of total hydrocarbons, water vapour less than 3.5 PPM and CO less than 1 PPM.

On site generation of clean air. Basic clean air generation needs the following components: oil-less compressor, desiccant to remove moisture, particle filter and activated charcoal filter/catalytic bed to remove other gaseous impurities. In addition a cooler may be required to drop the temperature of the compressed air, together with a storage tank.
The bottled gas approach is initially the cheapest method to start with, but the ongoing cost of the air will be excessive as production rates increase. The onsite method, while expensive to start with, will be the cheapest way in the long run.

The Calibration Chamber

There are two types of chambers – static and dynamic. In a static chamber, air and a known quantity of CO are introduced and then the chamber is sealed. A fan is required to ensure complete mixing of the two gases. The fan should be switched off when the calibration point for the detector is being established. In a dynamic chamber an air/CO mixture is introduced at a rate sufficient to establish and maintain the target CO concentration.
Materials of construction of the chamber should be relatively inert, such as glass, stainless steel, or Perspex. Joints should be sealed with inert sealing materials, i.e. preferably not containing silicone.

Carbon Monoxide delivery methods

Either direct injection of CO i.e. a static system, or a supply from a pre-diluted and calibrated gas cylinder can achieve the required concentration of CO.

Direct Injection. This method can only be used with static chambers. A pre-calculated volume of CO is injected into the closed chamber through a system of valves or through a septum using a suitable syringe.

Gas cylinder. A gas cylinder of the required CO concentration is connected to the chamber. The gas is allowed to flow until the whole volume of the chamber is at the required concentration. This approach may take up to 30 exchanges of gas volume to reach the final concentration.

A reference CO monitor should be available and compatible with the performance characteristics specified in ASTM Standard D3162. Some basic parameters are listed below:

Parameter	Specification
Range	0 to 500 PPM
Limit of detection	0.5 PPM
Zero drift	±1 % per day
Span drift	±1 % per day
Precision	±4 %
Temperature range	5° to 40° C
Linearity	2% Full Scale

Operating Temperature

The correct operating temperature of the Capteur CO sensor can be set by monitoring the sensor resistance value in clean air. The following systems can be used.

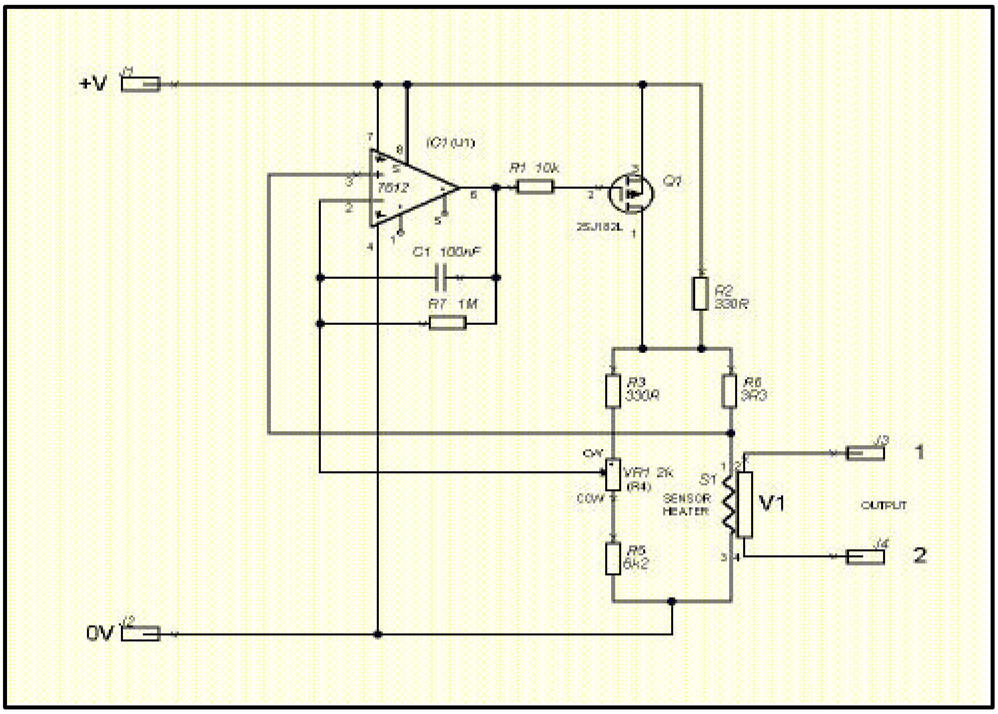


Figure 12

An analogue adjustable bridge circuit, as per the heater driver board. This involves adjusting the unit, manually or robotically, while powered up and within the test chamber, in clean air, <3% RH and 21°C (nominal), and reading the sensor value concurrently. (See Figure 12)

A bridge circuit controlled with a micro-controller derived pulse width modulated signal using an empirically established duty cycle based on the sensor reading in clean air at <3% RH and 21°C (nominal). It must be noted that the system should be running at a minimum of 4 MHz and with a resolution of at least 8 bits, 12 bits being ideal. An electronic (automatic) set up procedure can be used.

Sensor Interrogation

It is recommended that the sensor should not have a continuous potential applied across the electrodes. A current of no more than 30 micro-amps and an interrogation regime of 1 in 10 with the on period no greater than 50 milliseconds is suitable. In the event that a continuous voltage across the sensor is unavoidable, it should not exceed 0.1V.

Set Up Procedure

An ideal set-up procedure for CO detectors using the NGL07 sensor is as follows.
Using a test chamber with clean air at <3%RH and 21°C (nominal) present:
Set the sensor reading, by adjusting the heater, to the equivalent of 100K± 10KΩ (or as directed by Capteur).
Allow for 20 minutes stabilisation of the sensor resistance.
For analogue control the sensor resistance will need to be read into the micro controller system used by the detector.
For digital control of the sensor the duty cycles and the sensor resistance should now be loaded into memory.
Calibration can now continue with the relevant CO concentration.
Leave for 10-20 minutes (depending on gas concentration).
Load sensor resistance readings into memory and make detector operational.
Carry out final functionality test.

Restrictions

It is important to be aware of the following restrictions on the use of Capteur Sensors.

1. Do not use the sensors where there will be silicone vapours in the immediate environment. The silicone vapour will adsorb onto the surface of the sensing material and form a glassy (silicate) film thus preventing access by the target gas to the superficies of the sensor. The supplied carbon filter significantly reduces contamination threats. The user must therefore avoid exposure to such things as silicone adhesives, silicone oil spray, hair sprays, silicone rubber or putty. High concentrations of Formaldehyde based adhesives and foams can cause an increase in sensor resistance (false alarms), these are generally found in insulating foams, and new laminate worktops, this effect is not permanent.

2. Corrosive environments will not affect the physical construction of the sensors, as all exposed metals are noble metals. However continuous exposure to high concentrations of H_2S, HCl, SO_x and Cl_2 will have a detrimental effect on the sensing material.

Because any detector electronics would be configured to alarm on a pre-determined increase in sensor resistance, failure of the sensor or heater would be indicated as an alarm, i.e. the sensor fails safe with these types of faults.