CORRECTING FOR BACKGROUND CURRENTS IN FOUR ELECTRODE TOXIC GAS SENSORS

Introduction

This application note provides guidance on the correction of the zero background current within the temperature range from -30°C to +50°C using only the ambient sensor temperature and knowledge of the reference ambient calibration temperature.

Correction of the zero background can be relatively complex and the results obtained from these simple algorithms should be considered as the first step in a process to correlate sensor results to the gas concentration measured by a reference analyser. Secondary corrections may be required to correct any residual offsets to the calculated gas concentration to obtain the required accuracy. This application note describes only the primary correction to the zero background current.

Electrochemical amperometric gas sensors generate a background current in addition to the current from oxidation or reduction of the sampled gas. This background current is commonly called the **zero background current.** Zero background currents can be significant and can frustrate attempts to make measurements at low gas concentrations. Sources of these zero currents can include anodic or cathodic reactions on the working electrode (WE), electrochemical oxidation or reduction of the sensor electrolyte or electrolyte contaminants, and reduction of oxygen in the sampled air. The auxiliary electrode (AE) will also generate a current which mostly tracks the WE current.

If you have purchased Alphasense Individual Sensor Boards (ISB) or Analogue Front End (AFE) electronics, the calibrated offsets and sensor outputs will be expressed in voltage (mV) rather than current (nA). You will also have been provided with values for the electronic offsets for the WE (mV) and AE (mV) channels, and the Total Zero Offsets (mV) as a sum of the electronic offsets and the sensor offsets as determined in zero air at a temperature of 20 - 25 °C. These values will be required when calculating the corrected WE output.

Summary of Term definitions

WE_c = corrected WE output
WE_u = uncorrected raw WE output
AE_u = uncorrected raw AE output
WE_o = WE sensor zero, i.e. the sensor WE output in zero air
AE_o = AE sensor zero, i.e. the sensor AE output in zero air
WE_T = Total WE zero offset
AE_T = Total AE zero offset
WE_e = WE electronic offset on the AFE or ISB
AE_e = AE electronic offset on the AFE or ISB

n_T = temperature dependent correction factor for algorithm 1, refer to Table 3 for values
k_T = temperature dependent correction factor for algorithm 2, refer to Table 3 for values
k'_T = temperature dependent correction factor for algorithm 3, refer to Table 3 for values
k''_T = temperature dependent correction factor for algorithm 4, refer to Table 3 for values

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Initial calibration

1 If the sensors have been purchased on Alphasense AFE (Analog Front End) or ISB (Individual Sensor Board) electronics, then the following parameters will have been provided :

WE electronic offset, WE_e (mV)
AE electronic offset, AE_e (mV)
Total WE zero offset, WE_T, (mV)
Total AE zero offset, AE_T, (mV)
WE sensor zero (WE_o) = Total WE zero offset - WE electronic offset
AE sensor zero (AE_o) = Total AE zero offset - AE electronic offset
WE sensitivity in units of nA/ppb and mV/ppb. The latter will allow you to directly convert the mV output into ppb of gas.

Program your software with the supplied values. Remember to subtract the WE and AE electronic offsets from the raw WE and AE readings before correcting.

If you are using your own electronics, then first measure the open circuit voltage to determine your own board's WE and AE electronic offsets By default, Alphasense sets the electronic offsets on the AFE boards and ISBs to within the range 200 to 300 mV so that any zero sensor currents, either positive or negative about zero current can be measured as positive voltages.

Fit the sensor(s) to your board, apply power and allow several hours for the sensor to stabilise in ambient, clean air. Measure the outputs from the WE and AE channels, this will be your 'Total WE zero offset (WE_T)' and 'Total AE zero offset (AE_T)'. Note that the sensor will respond to any gases and VOCs in your ambient air. Alphasense calibrates zero current unsing "zero air" which is scrubbed air with no residual gases or VOCs.

2 Create a look-up table or other method in your software for determining the correction factor for your sensor at the measured sensor temperature (see table 3 for the complete list of temperature compensation factors). Correction factors are typically linearly interpolated between the temperatures listed in the Table.

3 Ensure that the temperature recorded as the sensor temperature is the temperature at the top of the sensor to within ±1 ^{o}C to ensure using the correct temperature compensation factor.

Table 1 : Algorithms to correct the WE output for the effects of temperature

Algorithm	Equation	Notes
1	$WE_c = WE_u - n_T * AE_u$	Directly scales the AE output. Gross under or over compensation can occur if AE_u is of opposite sign to n_T, or AE_u is significantly smaller or larger than WE_u.
2	$WE_c = WE_u - k_T * \left(\frac{WE_o}{AE_o}\right) * AE_u$	Scales AE by using the individual sensor calibration data. Gross under or over compensation will result If AE is very small or zero, or If WE_{cal} and AE_{cal} are of opposite signs, or the AE_T output is significantly smaller or larger than the WE_T output.
3	$WE_c = WE_u - (WE_o - AE_o) - k'_T AE_u$	Avoids the problem of Algorithm 2 with a zero AE_o value. Gross over or under compensation can result if AE_o is of opposite sign to WE_o, or if AE_o is significantly smaller or larger than WE_o.
4	$WE_c = WE_u - WE_o - k''_T$	Correction wihout using the AE_o result. Gross under or over compensation can occur if AE_u is significantly smaller or larger than WE_u.

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Table 2 : Suggested algorithms for both A type and B type sensors

Sensor	Suggested algorithm		Alternative algorithm	
	A	B	A	B
CO	1	1	4	2
H_2S	2	1	1	2
NO	3	2	4	3
NO_2	1	1	3	3
OX	3	1	1	3
SO_2	4	4	1 or 3	1 or 2

Correcting measurements and calculating gas concentration

1 Measure the WE and AE current (or voltage) in your application.

2 If using Alphasense AFE boards or ISBs, subtract the WE and AE electronic offsets from both the WE and AE total outputs. On your own boards, determine the sensor output by subtracting any offsets to obtain the actual sensor output.

3 Determine the temperature of operation, and from this temperature select the appropriate correction factor of n_T, k_T, k'_T or k''_T depending on which algorithm is to be used (Table 1).

4 Table 1 illustrates how each equation uses a different approach for how the sensor parmeters are combined. Table 2 is offered as a suggestion of which equation to use for a sensor type, but you are encouraged to explore the other models (equations) from Table 1. Each model has their own limitations and you may find your own optimum choice to better suit the conditions in which the sensor is used.

5 Divide the corrected WE result (WE_c) by the sensor's sensitivity to calculate the gas concentration. If desired, developers may wish to add a further refinement to the final gas concentration value by dividing the corrected WE output (WE_c) by a temperature corrected sensitivity instead of only the single ambient sensor sensitivity value provided. Each sensor type usually has a plot in its technical datasheet illustrating how the sensor sensitivity varies with temperature. Thus a complete temperature profile for the sensor type can be produced that corrects for background current changes (above) and sensitivity (or gain) changes due to temperature changes.

What next?

After applying the best algorithm, you may find the results do not meet expectations. Several factors may be skewing your results:

thermal transients can destabilise temporarily the sensor signal,
humidity changes and humidity transients (usually due to temperature transients) can also destabilise temporarily the sensor signal, and-
diurnal and seasonal temperature/ humidity patterns can shift calibration.

These uncontrolled variations will affect calibration: the sensors will adapt to a new environment, but the zero currents (WE_o and AE_o) will be different and sensitivity will change to a lesser degree. Sensitivity to other gases and VOCs may also shift, to a lesser extent.

Published papers explain how to use a network to correct for zero drift, and suppliers of AQ networks normally incorporate proprietary software that corrects for zero errors. Alphasense is developing correction algorithms that include this first level correction and go further.

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Table 3: Zero background current temperature compensation factors

Sensor	Algorithm	Factor	T / ºC -30	-20	-10	0	10	20	30	40	50
CO-A4	1	n_T	1.0	1.0	1.0	1.0	-0.2	-0.9	-1.5	-1.5	-1.5
	2	k_T	-1.1	-1.1	-1.1	-1.1	0.2	1.0	1.7	1.7	1.7
	3	k'_T	1.9	2.9	2.7	3.9	2.1	1.0	-0.6	-0.3	-0.5
	4	k''_T	13	12	16	11	4	0	-15	-18	-36
CO-B4	1	n_T	0.7	0.7	0.7	0.7	1.0	3.0	3.5	4.0	4.5
	2	k_T	0.2	0.2	0.2	0.2	0.3	1.0	1.2	1.3	1.5
	3	k'_T	-1.0	-0.5	0.0	0.0	0.0	1.0	1.0	1.0	1.0
	4	k''_T	55	55	55	50	31	0	-50	-150	-250
H2S-A4	1	n_T	3.0	3.0	3.0	1.0	-1.0	-2.0	-1.5	-1.0	-0.5
	2	k_T	-1.5	-1.5	-1.5	-0.5	0.5	1.0	0.8	0.5	0.3
	3	k'_T	9.0	9.0	9.0	9.0	3.0	1.0	0.3	0.3	0.3
	4	k''_T	50	46	43	37	25	0	-8	-16	-20
H2S-B4	1	n_T	-0.6	-0.6	0.1	0.8	-0.7	-2.5	-2.5	-2.2	-1.8
	2	k_T	0.2	0.2	0.0	-0.3	0.3	1.0	1.0	0.9	0.7
	3	k'_T	-14.0	-14.0	3.0	3.0	2.0	1.0	-1.2	-1.2	-1.2
	4	k''_T	52	51	48	45	26	0	-65	-125	-180
NO-A4	1	n_T	1.7	1.7	1.6	1.5	1.5	1.5	1.5	1.6	1.7
	2	k_T	1.1	1.1	1.1	1.0	1.0	1.0	1.0	1.1	1.1
	3	k'_T	0.7	0.7	0.7	0.7	0.8	1.0	1.2	1.4	1.6
	4	k''_T	-25	-25	-25	-25	-16	0	56	200	615
NO-B4	1	n_T	2.9	2.9	2.2	1.8	1.7	1.6	1.5	1.4	1.3
	2	k_T	1.8	1.8	1.4	1.1	1.1	1.0	0.9	0.9	0.8
	3	k'_T	0.8	0.8	0.8	0.8	0.9	1.0	1.1	1.2	1.3
	4	k''_T	-25	-25	-25	-25	-16	0	56	200	615
NO2-A43F	1	n_T	0.8	0.8	1.0	1.2	1.6	1.8	1.9	2.5	3.6
	2	k_T	0.4	0.4	0.6	0.7	0.9	1.0	1.1	1.4	2.0
	3	k'_T	0.2	0.2	0.2	0.2	0.7	1.0	1.3	2.1	3.5
	4	k''_T	-4	-4	-4	-4	-2	0	10	35	132
NO2-B43F	1	n_T	1.3	1.3	1.3	1.3	1.0	0.6	0.4	0.2	-1.5
	2	k_T	2.2	2.2	2.2	2.2	1.7	1.0	0.7	0.3	-2.5
	3	k'_T	1.0	1.0	1.0	1.0	1.0	1.0	0.4	-0.1	-4.0
	4	k''_T	7	7	7	7	4	0	0.5	5	67

Table 3 continues on next page...

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Table 3 continued

Sensor	Algorithm	Factor	T / ºC								
			-30	-20	-10	0	10	20	30	40	50
OX-A431	1	n_T	1.0	1.2	1.2	1.6	1.7	2.0	2.1	3.4	4.6
	2	k_T	0.5	0.6	0.6	0.8	0.9	1.0	1.1	1.7	2.3
	3	k'_T	0.1	0.1	0.2	0.3	0.7	1.0	1.7	3.0	4.0
	4	k''_T	-5	-5	-4	-3	0.5	0	9	42	134
OX-B431	1	n_T	0.9	0.9	1.0	1.3	1.5	1.7	2.0	2.5	3.7
	2	k_T	0.5	0.5	0.6	0.8	0.9	1.0	1.2	1.5	2.2
	3	k'_T	0.5	0.5	0.5	0.6	0.6	1.0	2.8	5.0	5.3
	4	k''_T	1	1	1	1	1	1	8.5	23	103
SO2-A4	1	n_T	1.3	1.3	1.3	1.2	0.9	0.4	0.4	0.4	0.4
	2	k_T	3.3	3.3	3.3	3.0	2.3	1.0	1.0	1.0	1.0
	3	k'_T	1.5	1.5	1.5	1.5	1.0	1.0	1.0	1.0	1.0
	4	k''_T	0	0	0	0	0	0	5	25	45
SO2-B4	1	n_T	1.6	1.6	1.6	1.6	1.6	1.6	1.9	3.0	5.8
	2	k_T	1.0	1.0	1.0	1.0	1.0	1.0	1.2	1.9	3.6
	3	k'_T	1.0	1.0	1.0	1.0	1.0	1.0	2.0	3.5	7.0
	4	k''_T	-4	-4	-4	-4	-4	0	20	140	450

Contact Alphasense to follow our progress.

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