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RELIABLE REFERENCING FOR FIXED AND MACHINE MOUNTED GAS DETECTORS

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ABSTRACT: Diffusion type gas detectors are used in fixed, machine mounted and handheld applications in underground mines for the real time detection of flammable and toxic gases. The calibration of a gas detector – typically by a 'bump' or 'challenge' test – sets the reference against which all subsequent measurements are taken. Failure to properly calibrate a detector will introduce errors into every subsequent measurement, regardless of the claimed accuracy of the instrument. The vulnerability of the calibration process to poor calibration mask design and to ambient air velocities has been established. The real problem, however, is knowing if and how the calibration process has been compromised. This paper discusses recent experiments showing the susceptibility of gas detection and calibration to poor calibration mask design and to ambient air velocities, and outline new research utilising a computational fluid dynamics approach to analysing calibration mask performance.

INTRODUCTION

Fixed and handheld diffusion type gas detectors are used to sample ambient atmospheres for the presence of flammable and/or toxic target gases. The performance of such detectors is characterized by standards such as AS/NZS 60079-29-1 (for flammables) and AS/NZS 4641 (for toxics and oxygen). Compliance to these standards is generally not mandatory. However, for heavily regulated applications (such as underground coalmines) the need for compliance to performance standards is typically enforced through regulation.

Both AS/NZS 60079-29-1 and AS/NZS 4641 prescribed accuracy and response time requirements under nominated test conditions. Original Equipment Manufacturers (OEMs) will typically submit new detectors for testing, with fresh factory calibrations and free from any contaminations or occlusions, thus obtaining the best possible performance results from the nominated and accredited test laboratory. End users, in turn, are often reliant on such test results to help select detectors for a given application. Comparisons of sensor accuracy and response time, environmental immunities and, of course, cost will all impact on decision criteria.

FIELD APPLICATION

In practice, the accuracy and response times of diffusion type detectors will be compromised through various permutations of:

- Drift of zero point due to ambient conditions (e.g. temperature, humidity, atmospheric pressure) affecting sensing elements
- Drift of zero point due to ambient conditions affecting embedded electronics
- Variation (reduction) of sensitivity of sensing elements due to ageing
- Variation of sensitivity of sensing elements due to contamination
- Variation of sensitivity of sensing elements due to partial blockages
- Variation of sensitivity of embedded electronics due to ageing

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- Variation of sensitivity due to ambient conditions

OEMs will usually provide guidance on the use and maintenance of such detectors to:

- Minimize the likelihood of the above factors affecting detector performance (preventative actions)
- Rectify the sources of performance deterioration (e.g cleaning filters)
- Compensate for the performance deterioration through field calibration

Such guidance might range from rudimentary inspections and cleaning of filter elements, through to testing and correction of detector zero and span readings under field calibration.

The vulnerability of field calibration

The absolute accuracy of a detector, as measured by an accredited laboratory, is validated by traceable calibrations of test equipment and the demonstrable competency of laboratory staff, often under a quality scheme such as The National Association of testing Authorities (NATA).

By comparison, the absolute accuracy of a detector calibrated in the field is totally reliant on both the competency of the operator, as well as the efficacy of the apparatus used to conduct the calibration. Experiments have shown that a number of factors can adversely affect field calibrations:

- Poor design of calibration masks (calibration cups)
- Poor fitment of calibration masks
- Incorrect flow rate of test gas
- Pressurisation of gas under the calibration mask (often by excess flow rate)
- Ambient air velocities diluting test gas concentrations
- Ambient air velocities over-exciting (catalytic) sensors

It is then quite possible that gas detectors in the field are routinely failing to perform to advertised levels of accuracy.

Poor design of calibration masks

Gas detector OEMs do not always apply the same degree of performance validation to calibration mask design compared with the detectors themselves.

Calibration masks are generally, but lamentably, disregarded as critical components in the gas detection safety system. Indeed, numerous anecdotes circulate describing the deployment of rags, rubber gloves, disposable drinking cups and other paraphernalia as makeshift calibration masks.

The principal function of a calibration mask (or cal cup) is to uniformly deliver a test gas to the sensing element, without imposing any physical or chemical disturbances that might introduce errors in the gas reading. Such disturbances might include contamination (such as silicones from tubing or rubber gloves), residual ‘sticky’ gases in the tubing or calibration masks, pressurisation of the gas at the sensor (see below), or temperature differences between test gas and ambient air.

The ideal calibration mask will deliver test gas to the sensing element at ambient temperature and pressure, in a homogeneous field at minimal velocity. (Some velocity is inevitable in order to introduce the test gas to the void.)

Factors to consider in the design of a ‘good’ calibration mask include:

- Fitment of the seal between the calibration mask and the gas detector: studies have shown that while sealing is not critical in laboratory environments with relatively still air, the impact of ambient air velocities typically found in underground mines will greatly inhibit the efficacy of the ensuing calibration.
- Design to accommodate all arrangements of the detector and its environmental housings: some OEMs provide calibration masks that require various ingress protection elements to be removed prior to calibration. The removal of these elements invariably changes the gas flows in the detector, resulting in optimisation in one configuration, but reduction in another.
- Management of flow rate: OEMs typically nominate a given flow rate for the test gas at which the calibration is to be undertaken. However, the mask (and procedure) should be designed with a significant robustness to varying flow rates caused by operator error of incorrect parts (such as flow rate regulators).
- Management of laminar and turbulent flows inside the mask: the shape, size and location of various orifices inside the mask can dictate whether the resulting gas flows are laminar or turbulent. Turbulent flows are desirable from the point of gas mixing; laminar flows can result in non-uniform gas concentrations inside the calibration mask.
- Locations of inlet and exhaust ports: the respective ports should be spatially separated to avoid ‘short-circuiting’ the gas flows directly from inlet to exhaust. The ports should be aligned to enhance gas mixing and uniformity inside the mask.
- The material(s) used the construction of the mask and connecting hoses should not react chemically with either test gases or with the sensing technologies deployed in the detector.

It is argued that performance validation of gas detectors should also mandate performance testing of OEM calibration masks and operating instructions to ensure end-users are provided with a demonstrably reliable calibration procedure.

Poor fitment of calibration masks

It is known that external air flow can impact the calibration process. Figure 1 shows three response curves for a single gas detector, using an identical test gas, but with different calibration masks and degrees of sealing.

A test gas of 2.43 % methane in air was delivered to a given detector via a calibration mask with a flow rate of 0.5 L/min. The reading was allowed to reach steady state before a 12 V fan was introduced to simulate external airflow past the calibration mask. The fan was placed at a distance of 200 mm behind the mask outlet, then 200 mm away at a 90° angle to the outlet, and then 200 mm away pointing directly at, and in line with the outlet. The fan was held at each location for 30 s. Finally, the fan was placed directly at the outlet.

The trace labelled ‘V1’ is a calibration mask designed for the given detector, but with a poor mating seal between mask and detector leaving a gap of 1mm. The impact of the moving air from the fan on measured gas concentration is substantial.

The trace labelled ‘V1 - Sealed’ is the same calibration mask, but with the previous gap sealed to prevent leakage between the mask and the detector. The improvement in measurement consistency is quite evident, even when subjected to the same series of imposed fan disturbances.

The trace labelled ‘V2’ represents an improved calibration mask design, with even greater immunity to fan (moving air disturbances). See Figure 2.

In each case, the calibration masks had an exposed exhaust port area equivalent to the inlet port area.

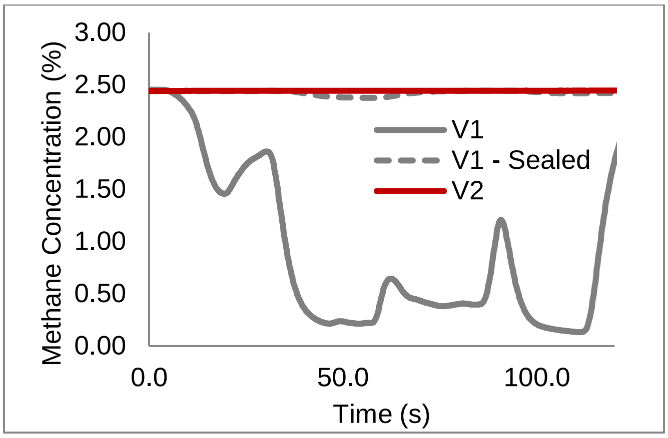


Figure 1: Sensitivity of methane detector to ambient air velocity. V1 has poor seal between calibration mask and gas detector exposing vulnerability to movement of surrounding air. (Steigler, 2019)

Figure 2: Calibration mask ('V2') designed for a particular gas detector using computational fluid dynamic analysis methods to optimise the resulting mask performance. (Steigler, 2019)

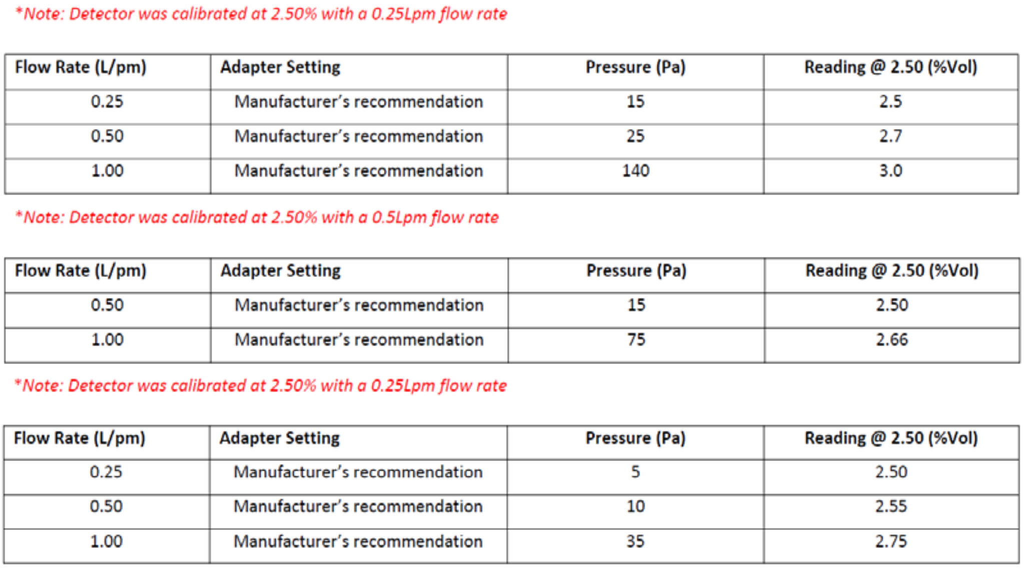
Incorrect flow rate of test gas

Table 1 shows the results of testing of a number of gas detectors to sensitivity against incorrect flow rate of test gas.

In each instance, the detector was calibrated in accordance with OEM instructions. The flow rate was then varied around the OEM nominal specification.

As can be seen (and might be expected), the measured concentration of the gas varied with flow rate.

Table 1: Sensitivity of a sample of gas detectors to varying flow rate of test gas. (Bale, 2013)



**Note: Detector was calibrated at 2.50% with a 0.25Lpm flow rate*

Flow Rate (L/pm)	Adapter Setting	Pressure (Pa)	Reading @ 2.50 (%Vol)
0.25	Manufacturer's recommendation	15	2.5
0.50	Manufacturer's recommendation	25	2.7
1.00	Manufacturer's recommendation	140	3.0

**Note: Detector was calibrated at 2.50% with a 0.5Lpm flow rate*

Flow Rate (L/pm)	Adapter Setting	Pressure (Pa)	Reading @ 2.50 (%Vol)
0.50	Manufacturer's recommendation	15	2.50
1.00	Manufacturer's recommendation	75	2.66

**Note: Detector was calibrated at 2.50% with a 0.25Lpm flow rate*

Flow Rate (L/pm)	Adapter Setting	Pressure (Pa)	Reading @ 2.50 (%Vol)
0.25	Manufacturer's recommendation	5	2.50
0.50	Manufacturer's recommendation	10	2.55
1.00	Manufacturer's recommendation	35	2.75

This sensitivity, however, need not be tolerated. Figure 3 shows the variation of measured test gas concentration against applied flow rate for the 'V2' mask. The exaggerated vertical scale magnifies the variability: 2.42% to 2.45% across a range of flow rates from 0.2 l/min to 1.0 l/min.

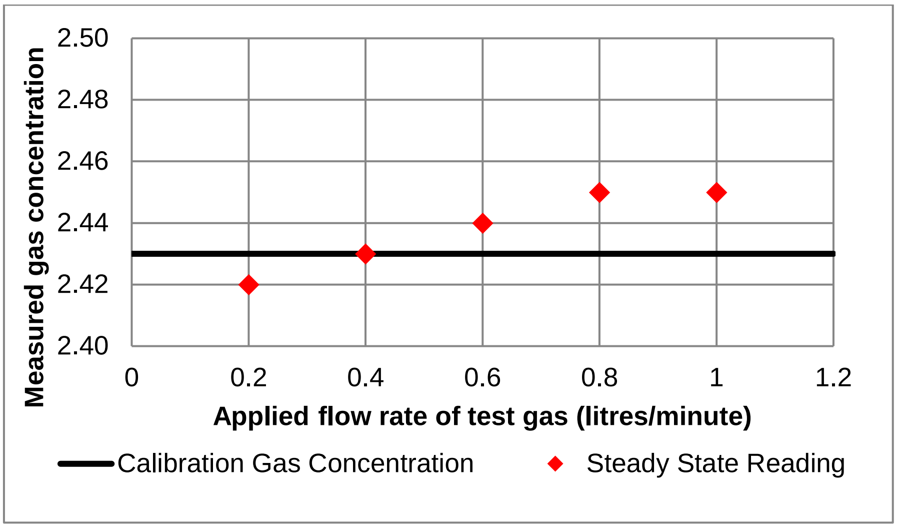


Figure 3: Sensitivity of a superior gas detector to variations in test gas flow rate. (Steigler, 2019)

While the application of test gas to a detector under test should be within OEM specifications, the immunity to variations in flow rate can be designed with due diligence.

Pressurisation of gas under the calibration mask

The results in Table 1 show both the measured gas concentration and the pressure of the test gas measured under the calibration mask. It is observed that when the test gas flow rate is varied outside of OEM specification, the pressure under the mask increases.

The ideal gas law PV = nRT dictates that all other variables being equal, an increase in pressure (P) will result in an increase in measured gas concentration (n).

The pressure rise observed in Table 1, then, is the result of poor calibration mask exhaust porting, resulting in an accumulation of test gas under the fixed volume mask.

Empirical studies have indicated that a well-designed calibration mask should have an exhaust port of equivalent (or greater) cross-sectional area than the mask's gas inlet. This ensures that pressure build-up under the mask is minimised.

Earlier versions[1] of AS/NZS 60079-29-1 (2008) contained reference to an ideal pressure limitation of 50 Pa[2] under the calibration mask. Limiting to this value ensured minimal pressurisation under the mask and so negligible effect on the measured gas concentration.

Ambient air velocities diluting test gas concentrations

The potential susceptibility of gas detectors and calibration masks to ambient air velocity was shown in Figure 1. In particular, when a gap existed between the calibration mask and the detector under test, the measured concentration was markedly reduced.

The reigning hypothesis to explain this observation is that the movement of the ambient air serves to evacuate the test gas from the calibration mask by venturi effect. In the experiment described, the gap was between the mask and detector body. Of course, other gaps, orifices or misalignments could also cause the same venturi effect.

It is relevant to recognise that this effect is difficult to observe in the field, where no frame of reference is available. Observation in a laboratory is easier, since invariably the ambient air is still, and can be forced by a controlled fan. It is crucial, then that the calibration process, equipment and technique be developed and validated under controlled conditions before application in the field (mine) where ambient conditions are essentially uncontrolled.

Ambient air velocities over-exciting (catalytic) sensors

In some instances, the introduction of moving air can apparently increase the measured concentration of gas – the reverse of the above venturi situation.

Catalytic methane detectors, unlike IR technologies, consume methane during the sensing process. Such detectors require a constant flow of methane, and oxygen, to sustain the oxidation process. Furthermore, the byproducts of the oxidation need to be exhausted from the bead surroundings.

In some situations the introduction of moving ambient air invigorates the oxidation process by one or more of:

- Forcibly introducing more methane to the catalytic bead
- Forcibly introducing more oxygen to aid the oxidation
- Evacuating the by-products of oxidation enabling the introduction of more methane and/or oxygen
- Selectively cooling the reference catalytic bead compared with the oxidising bead

Determination of the effect of ambient air velocities over-exciting (catalytic) sensors is again best undertaken in a controlled laboratory environment, where the effect of various air speeds and directions can be measured.

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[1] The reference to this value in AS/NZS 60079-29-1:2008 has since been deleted from the AS/NZS 60079-29-1:2018 version.

[2] This is equivalent to 5 mm of water at normal atmospheric pressure.

CONCLUSIONS

Given that ongoing detector performance is so reliant on correct calibration procedure, equipment and execution, it is argued that performance testing of detectors should include testing of the field calibration procedure.

Furthermore, the performance testing of calibration procedures should include all environmental conditions included in the performance testing of the detector itself. For example, if a given detector is performance tested in ambient air velocities up to 6 m/s, then the calibration procedure should also be tested under the same conditions.

If such performance testing was completed by an accredited laboratory as part of performance testing to a given standard, end users would have a higher degree of confidence in their application of the same procedure in the field.

The scenario painted begs the question as to how end-users can validate field calibrations. The following approaches are suggested:

- Ask your detector supplier to provide recommended field calibration kit and procedures.
- Ask your gas detector supplier if their field calibration kit and process has been performance tested under the same operating conditions as the detector itself.
- Validate the field calibration process in a laboratory against calibrated test equipment.

Validate the field calibration process in the field by the use of a second (calibrated) detector to compare ‘before’ and ‘after’ results of the equipment under test.

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