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FILTER REQUIREMENTS FOR GRAHAM'S RATIO OXYGEN DEFICIENCY

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ABSTRACT: Graham's ratio (GR) is used to calculate the amount of carbon monoxide produced in proportion to the amount of oxygen consumed by the coal. It is a useful indicator for Coal Mines to determine the level of coal oxidation and to respond accordingly in the event of spontaneous combustion. The intensity of the coal reaction is related to the carbon monoxide produced and the oxygen consumed (oxygen deficiency). Graham's ratio is very important as it is often used as a trigger for Trigger Action Response Plans (TARPs) for the management of spontaneous combustion. Samples with a similar composition to air may return a negative or minuscule measured oxygen deficiency unsuitable for Graham's ratio. The same problem is identified in samples diluted with seam gas or when there are inaccuracies in other measured components when nitrogen is calculated by difference and not directly measured. The issue arises when oxygen deficiency is inadequate and insufficient, where the GR result can be overestimated and trigger a TARP level. Some mine sites introduced a filter for minimum oxygen deficiency value to avoid alarm "fatigue" for a Control Room Operator (CRO). There are cases where this minimal value is not suitable and where valid oxygen values have been filtered. This paper will present the case studies where the filter value was adjusted to suit the mine site actual real data and analysis technique.

INTRODUCTION

Mines operating in Australia are responsible for managing and monitoring their own risks. The processes used to achieve compliance with Australian legislation are complex and well established. Each mine site develops its own Health and Safety system and Mines Principal Hazard Management Plan (PHMP) in order to identify and control principal hazards, such as spontaneous combustion. The data produced by a mine site gas monitoring system is a critical component in this process. Each mine has specific conditions and should base their trigger and alarm levels on what is a "normal" condition and not what is average level observed. The operational considerations for tube bundle systems (Watkinson, Bajic, Forrester, & Ryan, 2016) and consequences of misinterpreting trends (Watkinson & Bajic, Best Practice Gas Monitoring, 2019) were assessed by Simtars in past. To enable risk identification and early response, mines establish TARPs which outline trigger points and actions to prevent any incident from escalating.

Graham's ratio is often used as a trigger for TARPs for the management of spontaneous combustion. This emphasises the importance of accurate measurement of oxygen deficiency and the ability to successfully determine the status of an underground atmosphere. If the oxygen deficiency is inadequate and insufficient, the Graham's ratio result can be overestimated and trigger a TARP level. If the number of these false alarms is large, it can affect Control Room Operator (CRO) fatigue and introduce another risk of missing important non-false alarms (Bajic, Muller, & Gido, 2020).

Muller, et al., (2017) explains how raw carbon monoxide concentration is not always indicative of the intensity of a heating due to dilutions or accumulation of gases. By comparing carbon monoxide generated with oxygen deficiency, a more relative measurement can be made (Graham's ratio). This measurement is independent of air flow and various forms of the equation account for dilution effects (Cliff, etal., 1999).

In order to incorporate the initial gas readings, and to incorporate nitrogen by difference to ensure the effects of dilution are included, the following equation is applicable:

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Equation 1:

$$Graham's\ Ratio = \frac{100 \times \ (carbon\ \ monoxide_{final})}{(0.265 \times nitrogen_{final}) - oxygen_{final}}$$

Note that the constant 0.265 is simply the theoretical ratio of oxygen to nitrogen in air.

Equation 1 is commonly used to calculate GR on real time sensors underground. The assumptions in this instance are that the ratio between oxygen and nitrogen in the inlet stream is the same as in fresh air, and that inlet contains no carbon monoxide. This is not applicable for inlet stream that is depleted in oxygen, enriched in carbon monoxide or enriched in nitrogen.

It is very important for a mine to establish a database for its deposit individual conditions. Using a measured fresh air value and taking dilution into account is represented by the equation 2:

Equation 2:

$$Graham's\ \ Ratio = \frac{100 \times \ \left(carbon\ \ monoxide_{final} * \frac{nitrogen_{final}}{nitrogen_{initial}}\right) - carbon\ \ monoxide_{initial}}{\left(oxygen_{initial} \times \frac{nitrogen_{final}}{nitrogen_{initial}}\right) - oxygen_{final}}$$

Equation 2 is a common equation used to calculate Graham's ratio for tube bundle monitoring points in underground coal mines. The measured fresh air point is typically obtained from a point on the surface at the tube bundle building, or from an intake roadway underground. More detailed explanations are presented in Muller, et al., (2017).

The final oxygen value can never exceed initial oxygen, as oxygen is not generated underground. Analysing equipment has a typical tolerance of +/- 0.2 % and therefore a small error is expected. This occasionally can lead to higher final oxygen readings than initial oxygen readings. Negative oxygen readings will produce a negative Graham's ratio, which is impossible result.

Muller, et al., (2017) states that current practice at mine sites is to apply the minimal oxygen deficiency requirement of 0.3 %, which eliminates the majority of non-reliable data points. Graham's ratio is previously understood to be unreliable for oxygen deficiencies below 0.3 % (Brady, 2007). Strand (1985) state that the calculation is subject to analytical limits and that oxygen deficiency of less than 0.2 % would introduce gross errors. As the technology advanced since 1985, it is now possible to investigate, with greater confidence, the threshold value for this equation.

One of the mine disasters in the Queensland Moura region occurred on 7 August 1994 at Moura No 2 Mine. On this occasion eleven miners died as a result of an explosion. Moura No 2 mine is on the eastern side of the Bowen Basin in the state of Queensland 7 km to the east of the town of Moura. The Inquiry found that the first explosion originated in the 512 Panel of the mine and resulted from a failure to recognise, and effectively treat, a heating of coal in that panel. (Windridge, Parkin, Neilson, Roxborough, & Ellicott, 1996)

The analysis of Moura 2 mine disaster data provides evidence that filters over 0.2% are not suitable for every location. An investigation performed by Muller, et al., (2017) indicated that an oxygen deficiency of less than 0.3 % may still be reliable in some situations and generate critical data for underground air monitoring.

METHODOLOGY

Pre and post explosion data from the Moura No. 2 mine disaster was used for filter demonstration purposes. As per conditions set in Muller, et al., (2017), the minimum oxygen deficiency value selected was 0.05 %, as this value appears to be the lowest and most conservative value. Data in the form of tube bundle logs were obtained from gas monitoring software. Bajic, et al., 2020 provided examples of data obtained from two underground coal mines in Australia, which had previously experienced and flagged invalid Graham's ratio triggers in their alarm logs and had their filter threshold points were set to 0.05 %. The locations containing low oxygen deficiencies (around 0.5 % or less) were chosen for the study.

Each relevant data log was extracted to a comma separated values file (CSV) containing the following information:

- Date and time of measurement and monitoring point number (location)
- Methane, Carbon Monoxide, Oxygen and Carbon Dioxide concentrations (%)
- Carbon Monoxide Make (litres per minute)
- Graham's ratio – calculated
- Selected fresh air point was pump room.

In addition to these gas components, the Graham's ratio calculated from the gas monitoring software, as per industry standards, was extracted with each set of gas readings (Muller, et al., 2017). These extracted data logs were processed in order to calculate a theoretical oxygen deficiency and theoretical Graham's ratio values based on fresh air as the initial readings for real time data, and the fresh air point for tube bundle data. For several tube bundle locations the measured initial air values were used rather than the theoretical initial values. This allowed the Graham's ratio calculation to be replicated as accurately as possible, reproducing the actual values calculated by the mine site monitoring system before extraction. Locations processed were 512 seals and return.

The calculated Graham's ratio value for each measurement was categorised based on the following thresholds:

- Normal data was defined as any data with corresponding theoretical Graham's ratio calculated at 0.2 or below. This range is often used as normal conditions for spontaneous combustion management TARPs in Queensland mines (Mines Rescue Gas Detection and Emergency Preparedness 2014).
- Investigate data is defined in this testing as any data with theoretical Graham's ratio calculated at 0.2 to 0.4. This range is often used as an 'investigate' trigger for spontaneous combustion management TARPs in Queensland mines (Mines Rescue Gas Detection and Emergency Preparedness, 2014).
- An invalid trigger is defined as any data with theoretical Graham's ratio calculated at over 0.4 without a corresponding significant increase in carbon monoxide or CO make.
- A valid trigger is defined as any data where the theoretical Graham's ratio is calculated at over 0.4 with a corresponding significant increase in raw carbon monoxide or CO make associated with the data. By definition, any Graham's ratios over 0.4 which are not valid triggers are considered invalid.

Filtering of tube bundle and real time data sets were based on minimum oxygen deficiency set points. Overall data retention, retention of normal data, investigate data points removed, invalid data points eliminated and valid data points eliminated were evaluated for each filtered data set.

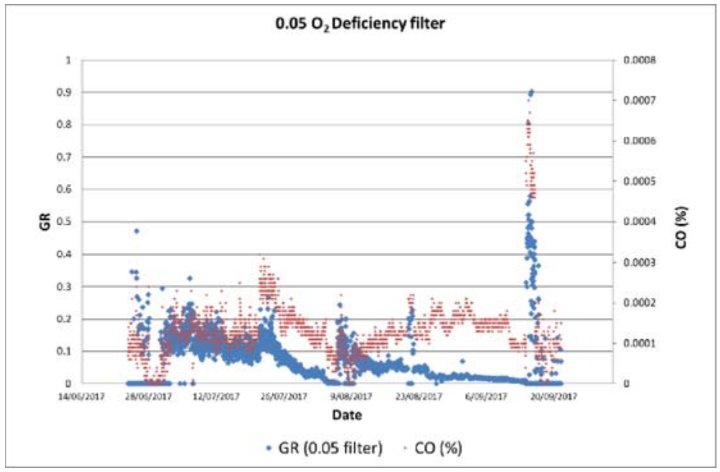
RESULTS AND DISCUSION

Previously evaluated data was based on feedback from two selected mines. (Bajic, Muller, & Gido, 2020) The locations showed the need to adjust applied filters in order to reduce control room operator alarm fatigue. In this paper the aim was to show how a large inadequate filter, should it have existed at the mine at the time when the spontaneous combustion started, would cause the mine to have missed the spontaneous combustion event and thus reacted late.

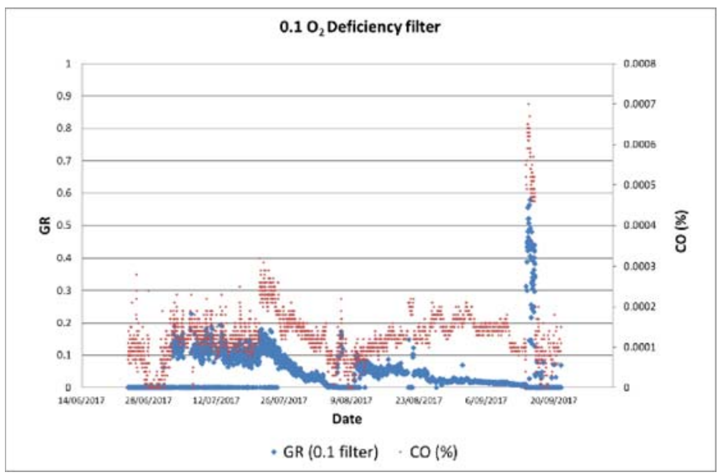
In previously provided examples (Bajic, Muller, & Gido, 2020), if higher filters were applied (0.2 % and above) to a particular location, there would be no invalid triggers in a selected period, while a lower than 0.2% filter would retain invalid triggers. The mine investigated this instance and confirmed that the GR alarm values were invalid triggers, and there were no corresponding significant increases in CO or CO make. Furthermore, in another period, over 30 GR alarms were noted. The 0.05 % filter included these values and the mine investigated the situation. In this case there was an increase in CO and CO make, confirming valid triggers in GR ratios. If higher filters were applied in this case there would have been the possibility of valid data being lost. Applying a filter at 0.1 % would still remove 100 % of invalid data, and retain 89.20 % of valid triggers, while higher filters, 0.2 % and above, would retain 100 % of valid triggers from this period (Figure 3). Reduction of suspected triggers "investigate" is optimised with a 0.1 % filter (85.79 %), while a 0.05 % filter only reduces 54.64 % of suspected "investigate" data points.

To provide insight into the relationship between oxygen efficiency, CO and GR, Figure 4 displays two possibilities:

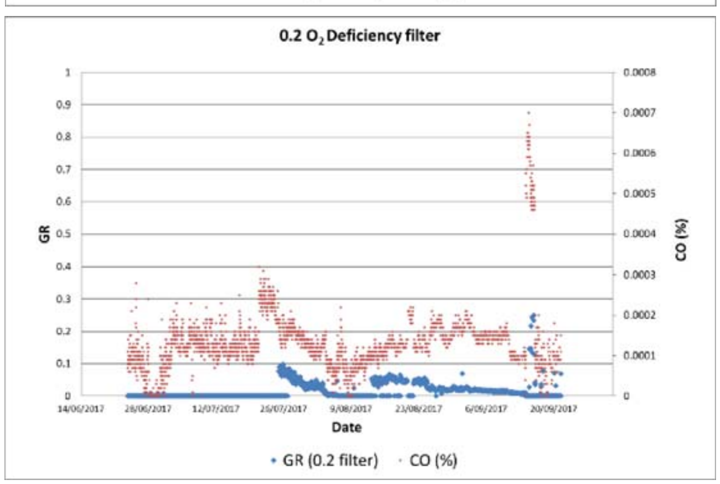
- Constant CO value at 8 ppm for the entire period
- Increasing CO values from 5 ppm to 60 ppm



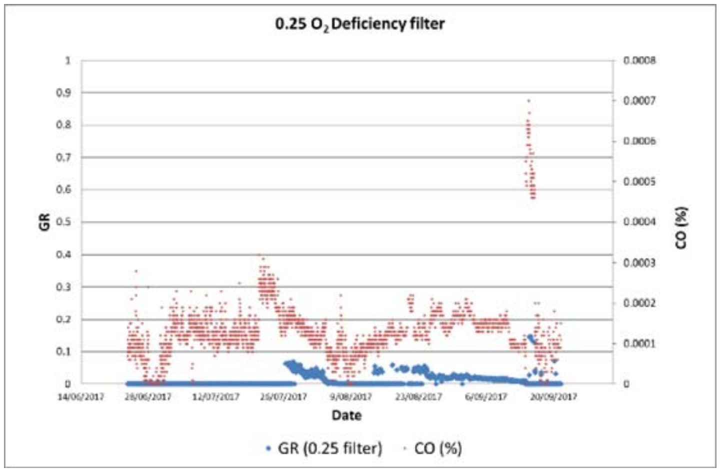
a



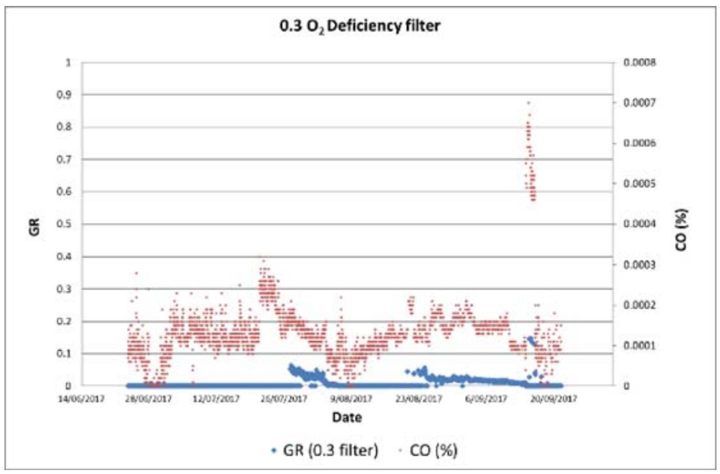
b



c



d



e

Figure 3: Case study, Grahams ratio (applied oxygen deficiency filter (%) 0.05 (a), 0.1 (b), 0.2 (c), 0.25 (d) and 0.3 (e), with CO (%) (Bajic, Muller, & Gido, 2020)

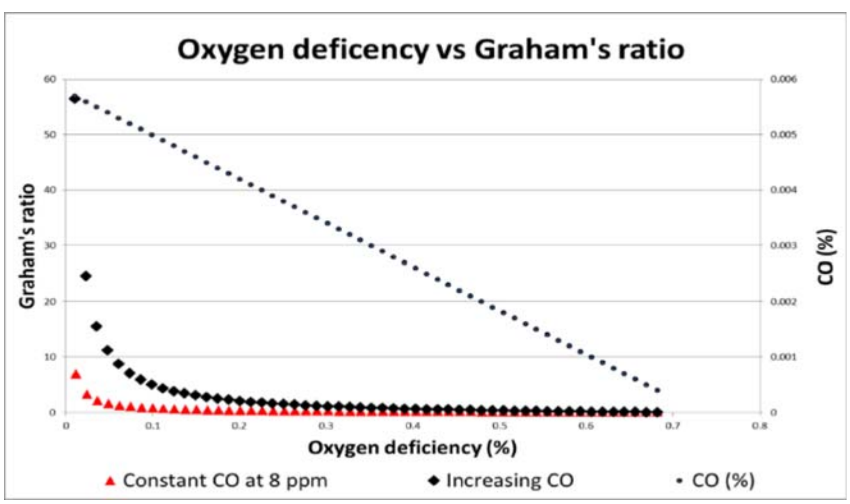


Figure 4: Oxygen deficiency and GR relationship, with 8ppm CO and increasing CO values

It is clear that the relationship between GR and oxygen deficiency is exponential below 0.05 oxygen deficiency in both scenarios. Values between 0.1 and 0.3 oxygen deficiency are more conservative and will retain more data points. The relationship appears to be more linear until approximately the 0.3

oxygen deficiency point. This data indicates that the trend and filtering depends on location and situation, and should not be considered in isolation. CO and CO make values need to be considered as well. Furthermore, Figure 5 presents tube bundle data from one mine site where GR was valid and increased with increased CO. Figure 6 shows data where GR values were increased while CO remained low and stable indicating invalid GR.

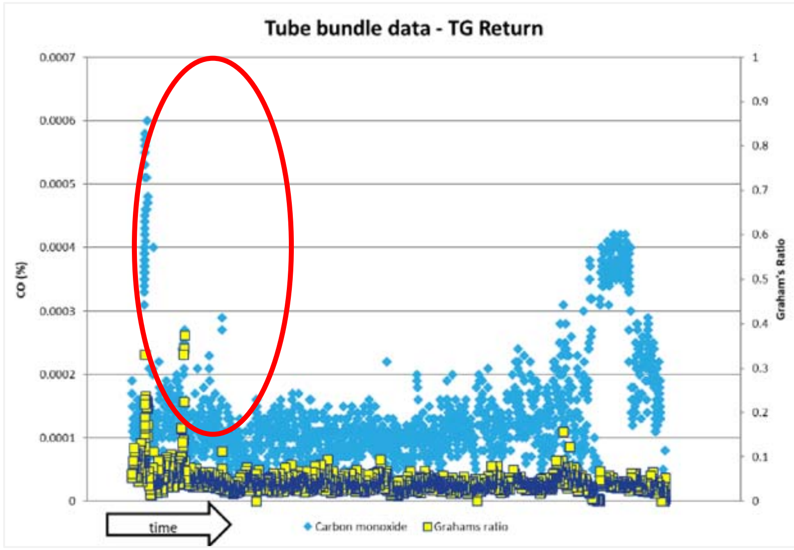


Figure 5: Valid GR, with increasing CO

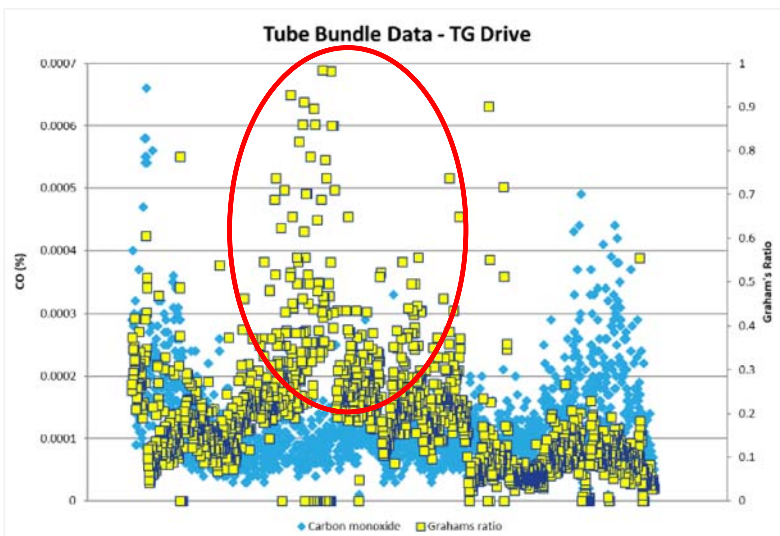


Figure 6: Invalid GR, stable low CO

When Moura No.2 data was processed, it was evident that majority of oxygen deficiency values were lower than 0.05% (Figure 7). If the mine had an oxygen deficiency of 0.3%, as it is commonly applied in mines today, the mine would not be able to see an increased valid GR (Figure 8).

In this case it is not appropriate to consider data in isolation of CO and filtered with a large (0.3%) filter. Although CO values were not high (5-15ppm) in the days leading to the explosion (Figure 9) there is an increasing trend of CO indicating oxidation.

Figure 10 presents oxygen deficiency (before and after the explosion), GR and CO (ppm). Oxygen deficiency and CO are on primary axis, while GR is on secondary axis. It is evident that data trended like this, non-filtered, would present valid triggers.

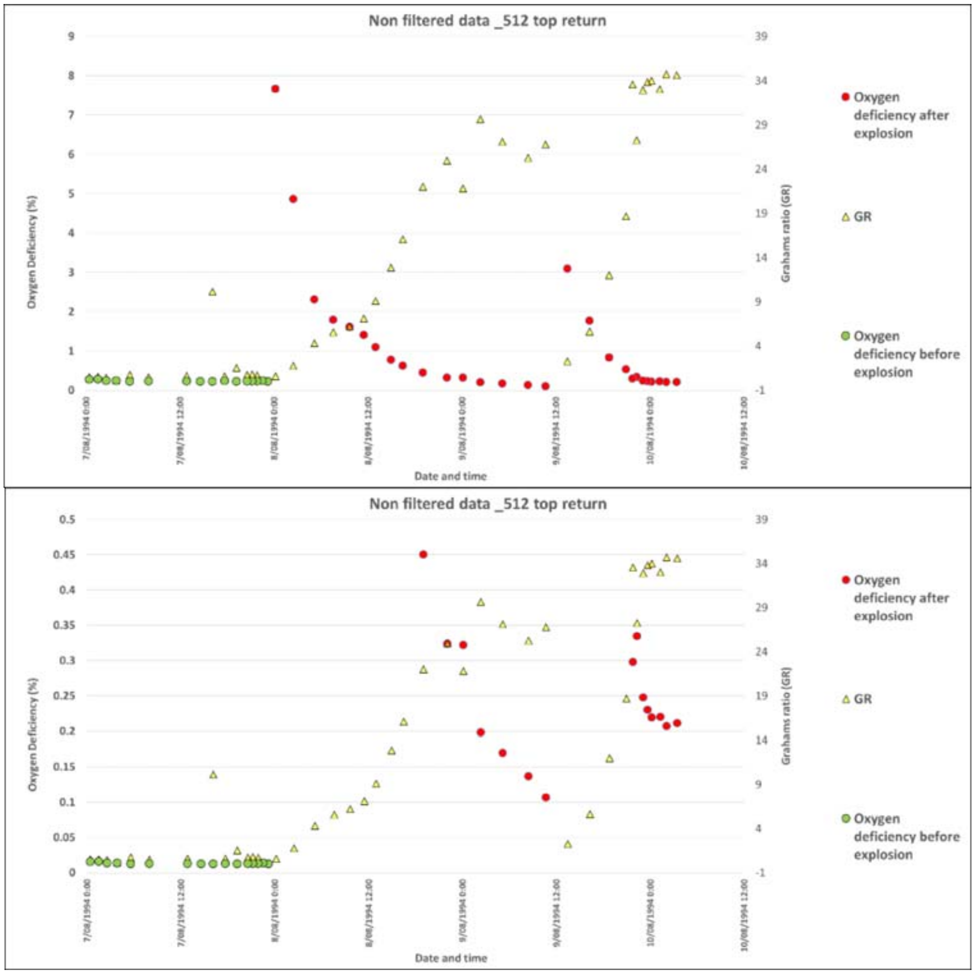


Figure 7: Moura No.2 512 top return data, before and after explosion (all data and increased oxygen deficiency resolution)

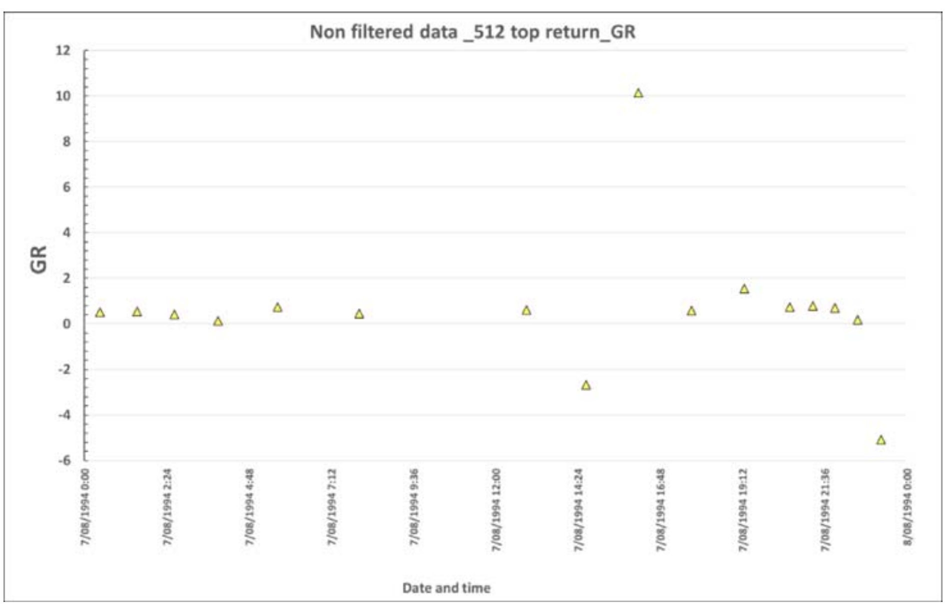


Figure 8: Moura No.2 512 top return data, GR before and after explosion

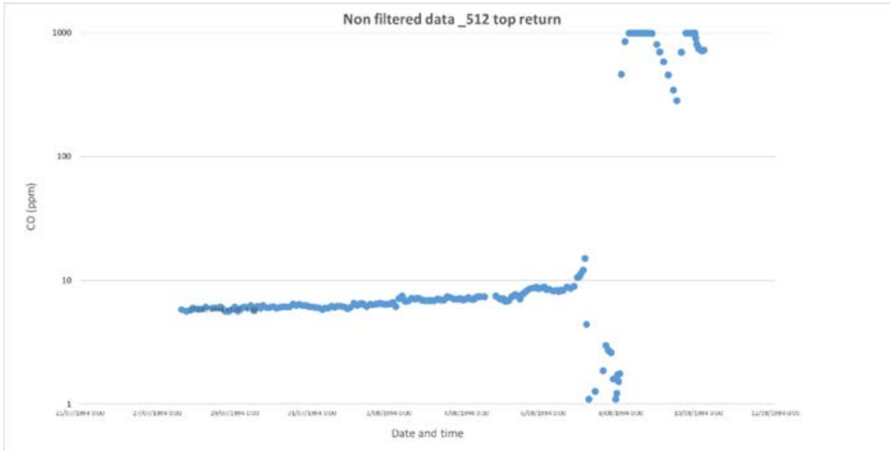


Figure 9: Moura No.2 512 top return data, CO (ppm) before and after explosion

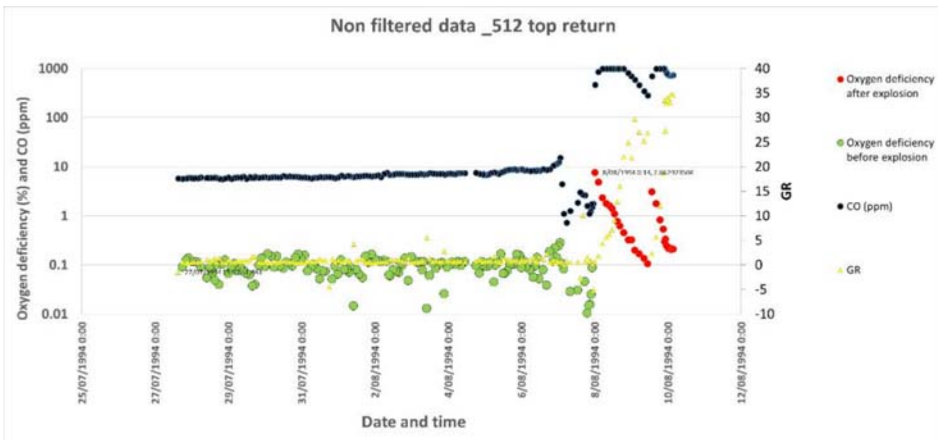


Figure 10: Moura No.2 512 top return data (combined), before and after explosion

CONCLUSIONS AND RECOMMENDATIONS

The data presented in this paper clearly shows that a minimal oxygen deficiency of 0.3% leads to an indiscriminate loss of potentially valid data for atmospheres close to air. As previously stated, the optimal oxygen deficiency filter is most likely dependant on mine deposit, individual database and measurement technique (instruments). Further, it is possible that different locations may require different filter points. Data should not be considered in isolation from other indicators, such as CO and CO make. Additional filters for CO and CO make could be considered in addition to an oxygen deficiency filter for the GR ratio trigger alarm. These parameters could also be included in TARPs together with Graham’s ratio. Further testing and investigation is required for optimal alarm threshold points. Based on the presented data set, a threshold value of 0.30 % did not appear optimal.

ACKNOWLEDGMENTS

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REFERENCES

Bajic, S., Muller, S. & Gido, M., 2020. Oxygen deficiency in Graham's ratio, evaluation, University of Wollongong (UOW): Coal 2020. pp. 314-320. [https://ro.uow.edu.au/coal/783/]

Brady, D., 2007. The Influence Analytical Techniques and Uncertainties in Measurement Have on the Assessment of Underground Coal Mine Atmospheres, s.l.: QMIHSC.

Cliff, D., Hester, C. & Bofinger, C., 1999. The Interpretation of Mine Atmosphers particularly for Spontaneous Combustion, Mine Fire and Explosions. Redbank: SIMTARS.

Muller, S., Ryan, L., Hollyer, J. & Bajic, S., 2017. Review of Oxygen deficiency requirements for Graham's ratio, s.l.: Coal 2017, Wooloongong .pp.382-390. [https://ro.uow.edu.au/coal/676/]

NSW Mines Rescue, 2014. Mines Rescue Gas Detection and Emergency Preparedness. s.l.:s.n.

Strand, M.-W., 1985. A Manual on Mines Rescue, Sfaety and Gas Detection. s.l.:CSM Press.

Watkinson, M. & Bajic, S., 2019. Best Practice Gas Monitoring, s.l.: Queensland Mining Industry Safety and Health Conference .pp.405-417. [https://ro.uow.edu.au/coal/626/]

Watkinson, M., Bajic, S., Forrester, L. & Ryan, L., 2016. Operational Conciderations For Tube Bundle Gas Monitoring System, s.l.: Coal Operators' Conference, University of Woolongong. .

Windridge, F. et al., 1996. WARDENS INQUIRY: Report on an accident at Moura no 2 Underground mine on Sunday, 7 August 1994, s.l.: s.n.