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An improved technique for monitoring explosibility of gases

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AN IMPROVED TECHNIQUE FOR MONITORING EXPLOSIBILITY OF GASES

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ABSTRACT: Monitoring the potential for explosion in an underground coal mine traditionally centres on using the Coward Triangle, the Hughes Raybould Diagram, the USM explosibility diagram or the Ellicott diagram. None of these allow for analytical trending over time, it is difficult to determine rates of change of gas atmospheres using these techniques and thus predict if and when an atmosphere may become explosive. The Ellicott X Y diagram was an attempt to overcome this, This diagram suffers from the lack of bounds and the absence of an easy way to link the values to the limits of reality eg, fresh air, completely inert or completely fuel rich. In addition it requires separate plotting of the two parameters X and Y against time. Mines rescue guidelines and re-entry guidelines outline zones for safe entry and zones for no entry. Plotting these zones accurately on the X Y diagram is problematic, as there are four zones of interest – air rich, fuel rich, explosive and inert. Each of the three non-explosive zones would have different X and Y values to set as alarm points, making simple graphics impossible. This paper outlines a novel technique that allows for the plotting of the percent flammability independent of which zone the gases are in and indicating the zone separately. This enables easy time based trending to occur. This should enable wider acceptance and better understanding of explosion risk

Monitoring the potential for explosion in an underground coal mine traditionally centres around using the Coward Triangle, the Hughes Raybould Diagram, the USM explosibility diagram or the Ellicott diagram. None of these allow for analytical trending over time, it is difficult to determine rates of change of gas atmospheres using these techniques and thus predict if and when an atmosphere may become explosive. The Ellicott X Y diagram was an attempt to overcome this, This diagram suffers from the lack of bounds and the absence of an easy way to link the values to the limits of reality eg, fresh air, completely inert or completely fuel rich. In addition it requires separate plotting of the two parameters X and Y against time. Mines rescue guidelines and re-entry guidelines outline zones for safe entry and zones for no entry. Plotting these zones accurately on the X Y diagram is problematic, as there are four zones of interest – air rich, fuel rich, explosive and inert. Each of the three non-explosive zones would have different X and Y values to set as alarm points, making simple graphics impossible. This paper outlines a novel technique that allows for the plotting of the percent flammability independent of which zone the gases are in and indicating the zone separately. This enables easy time based trending to occur. This should enable wider acceptance and better understanding of explosion risk

BACKGROUND

Traditionally explosibility assessments in mining regulations have been cast in terms of the Lower Explosive Limit (LEL) of methane – 5% in air. Various explosion risk zones, and trigger points for the safe use of equipment and access by people have been gazetted in terms of this value. Modern mining regularly has to cope with situations where the atmosphere is well above the LEL and indeed may be well above the Upper Explosive Limit (UEL). Situations arise

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such as equipment (eg, borehole cameras) are being deployed into longwall goafs where the atmosphere is essentially pure methane. Currently if the equipment is not certified intrinsically safe by an Australian testing laboratory, the regulations prohibit its use. Highwall mining with inertisation may get into situations where the methane concentration exceeds the LEL but there is no oxygen present. In both cases there is no risk of explosion as there is no oxygen present. There is a need however in those situations to track any deviation in the atmosphere particularly if it trends toward an explosive atmosphere.

Currently representation of explosibility is best done graphically, with the Coward triangle and Ellicott diagram most commonly used in Australia however elsewhere the USBM Flammability Diagram is used. A full description of the various techniques can be found in many texts including Cliff, Brady and Watkinson, 2018.

The Coward Triangle plots the percentage of oxygen against the total percentage of flammable gases in the sample of interest (Figure 1). The three critical limits are all calculated for the particular sample from which the four zones; explosive, fuel lean, fuel rich and non-explosive are all determined and delineated on the diagram (Figure 2). The total flammable gas and oxygen concentrations in the sample of interest allow a datum point to be plotted on the triangle, indicating the explosibility status for that sample.

The expected behaviour of the gas mixture's explosibility status under various scenarios can be predicted as illustrated below (Figure 3). Adding fresh air makes the point head toward the top left corner of the triangle (20.95% oxygen). Adding inert gases makes the point head toward the bottom left corner (no oxygen and no flammable gas). Adding more combustible gases makes the point head toward the bottom right corner of the triangle (100% flammable gas). The triangle limits are fresh air (20.95% Oxygen), inert gas and 100% flammable gas.

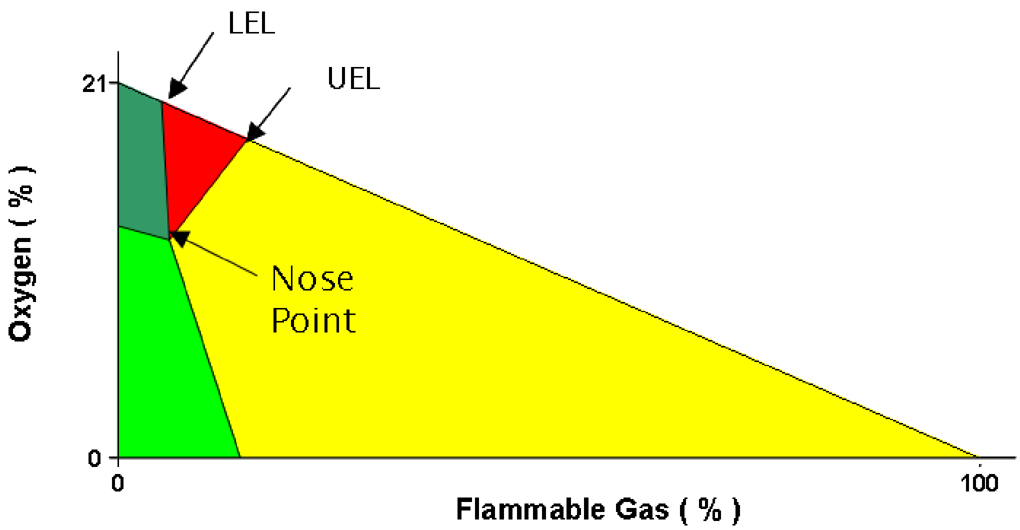

Figure 1: Coward Triangle (Cliff et al, 2018)

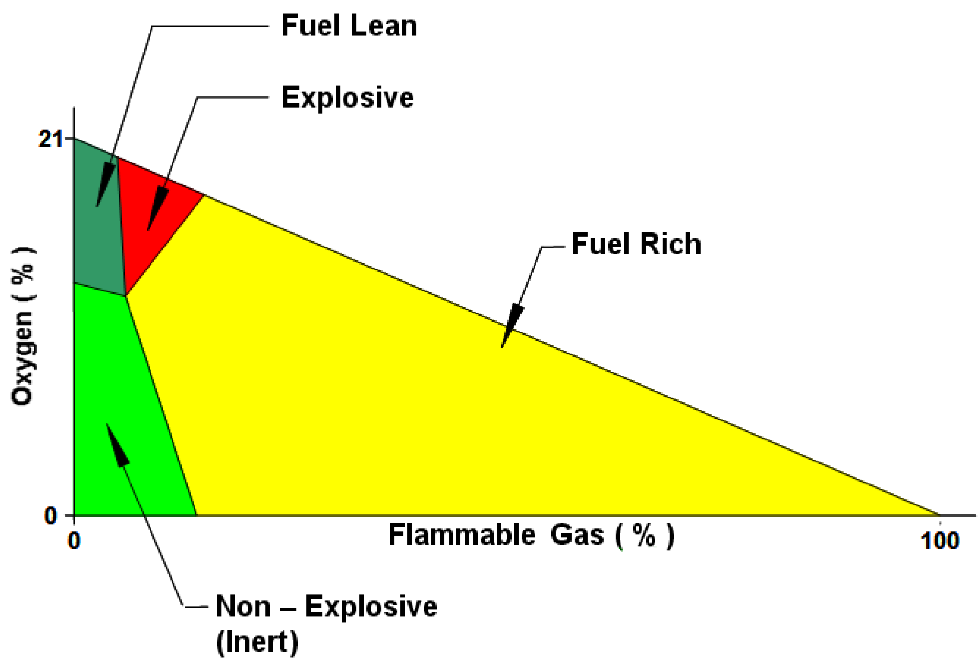

Figure 2: Zones on the Coward Triangle (Cliff et al 2018)

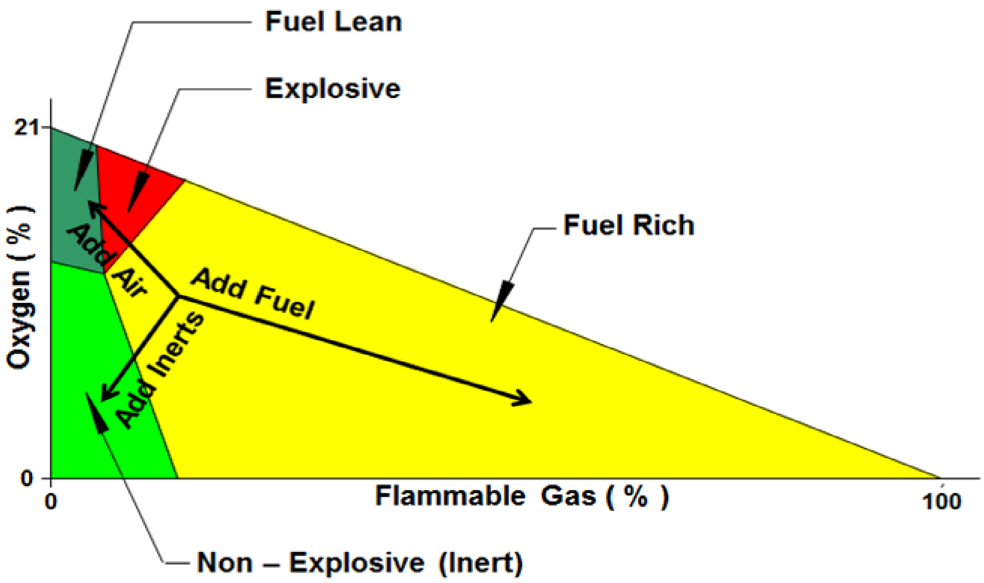

Figure 3: Trends on the Coward Triangle (Cliff et al 2018)

The work done by Coward was just for methane however Hughes and Raybould (1961) utilised Le Chatelier's additive principle (1891) to determine the upper and lower explosive limits for a sample with a mixture of flammable gases weighted by the concentration of the individual concentrations of the flammable gases.

The Ellicott diagram is a modification of the Coward Triangle. The triangle is transformed into a rectangle, with the centre point being the nose point (the point of minimum explosibility) and the axes radiating from there being the delineating barriers of each of the four different explosibility classifications (Figure 4);

- The + Y axis delineates the fuel lean zone from the explosive zone,
- The + X axis delineates the explosive zone from the fuel rich zone,

- The - Y axis delineates the inert zone from the fuel rich zone and
- The –X axis delineates fuel lean zone from the inert zone.

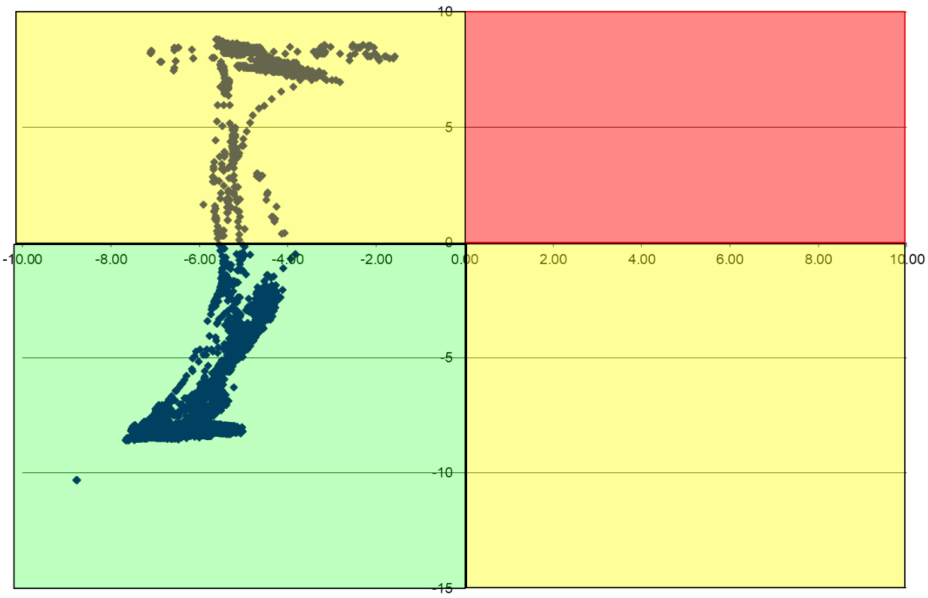

Figure 4: Ellicott diagram

As the Ellicott diagram is a distortion of the Cowards triangle with fixed sized zones, caution must be taken when assessing the explosibility status of a sample in relation to how close it is to other zones. There are only certain areas where it is possible for a plot to occur. Figure 5 shows the valid region for methane, hydrogen and carbon monoxide mixes with air on the one Ellicott diagram.

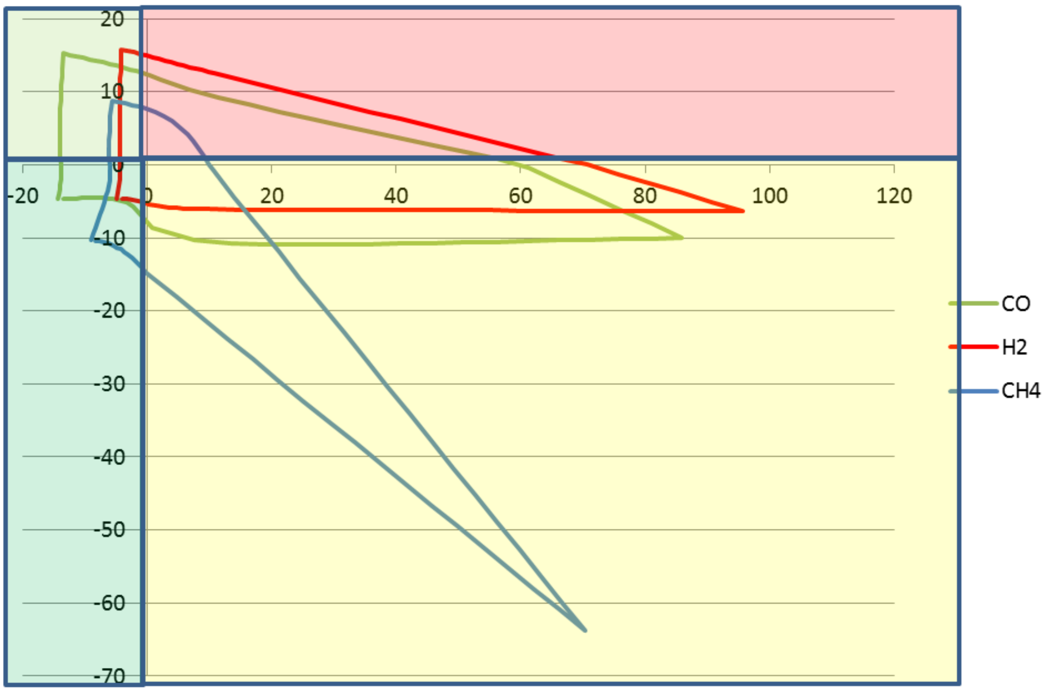

Figure 5: Limits of the Ellicott diagram

Many common modern depictions of the Coward and Ellicott diagram include zones that align with Trigger Action Response Plans (TARPs) and assist in the management of the flammability risk. Mines Rescue guidelines also utilise these zones in determining whether or not rescue teams can deploy. Figure 6 indicates such zones

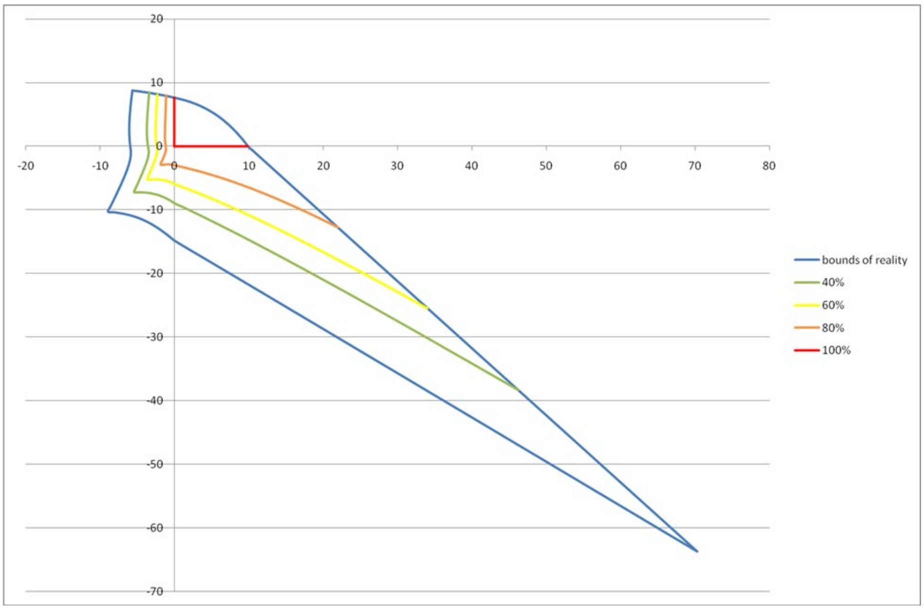

Figure 6: Explosibility safety margins for methane air mixes

Although trending is possible on a Coward triangle or an Ellicott diagram there is no means of incorporating a time scale. On an Ellicott diagram for a gas to be explosive it must have a positive X and Y value. By extracting the values for Ellicott X and Y from the software generating the plots, it is possible to plot both against time and make a prediction of not only if the location is going to become explosive but when as seen in Figures 7.

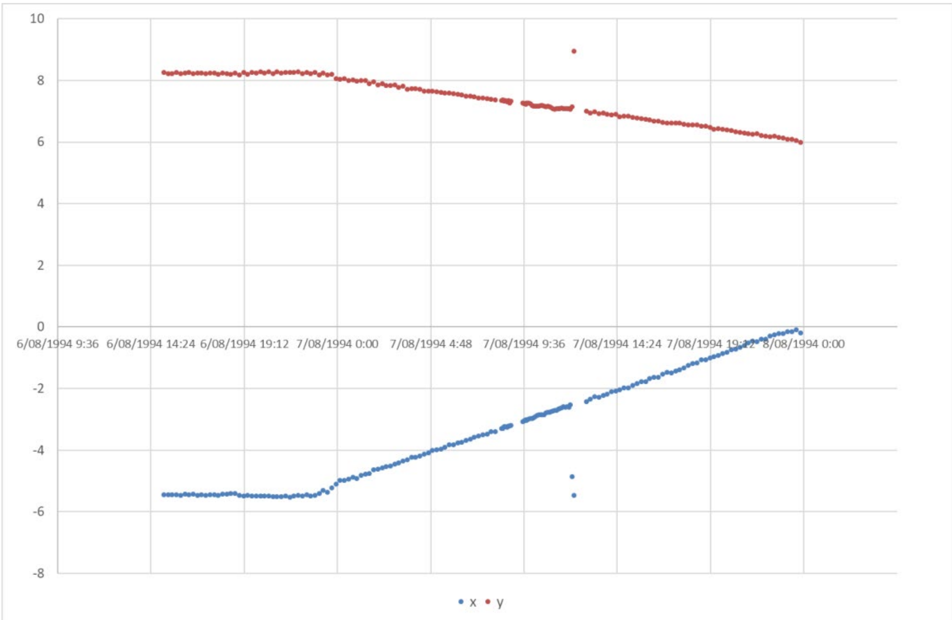

Figure 7: Ellicott X and Y diagram

The limitation of this technique is not knowing the proximity of the data to boundaries of the diagram and establishing the relationship to the TARPs.

THE NEW EXPLOSIBILITY DIAGRAM.

To overcome these issues a diagram was developed that overtly displayed the percentage of the explosive limit for the data point as a function of time. Colour coded data points were used to explain in which zone of the Coward triangle the data was based. The percentage explosibility was simply estimated from the percentage along the shortest line linking the closest boundary to the nearest explosive limit line passing through the data point (b/a as % in diagram below). An example is shown graphically below. In general this line is perpendicular to the explosive limit line. In the areas where this is not possible (as in Figure 8) then the line linking either the LEL, UEL or nose point to the boundary was used.

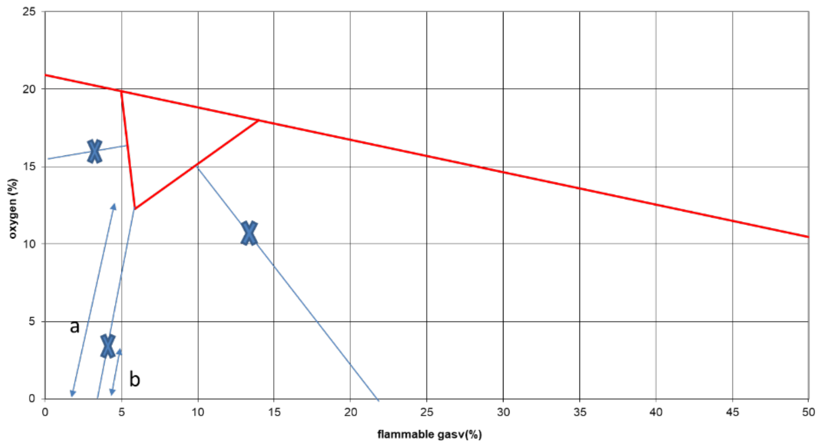

Figure 8: Calculating the percent flammability

Using the traditional colours from the Coward triangle this can now be plotted against time. The diagram below (Figure 9) illustrates this for a highwall mining operation using inertisation to manage the flammability risk. The yellow indicates that it starts out in the fuel lean zone from fresh air and transits to the inert zone (green). The traditional Coward triangle and Ellicott X Y plots are shown for comparison (Figures 10 and 11).

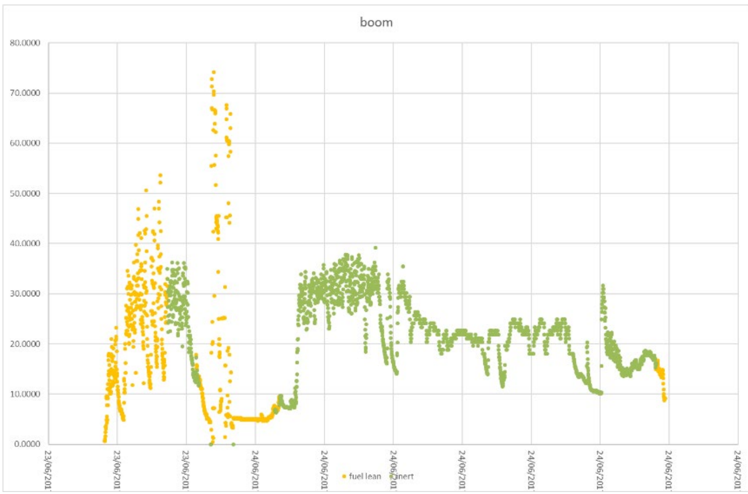

Figure 9: Explosibility time diagram for a highwall mining operation

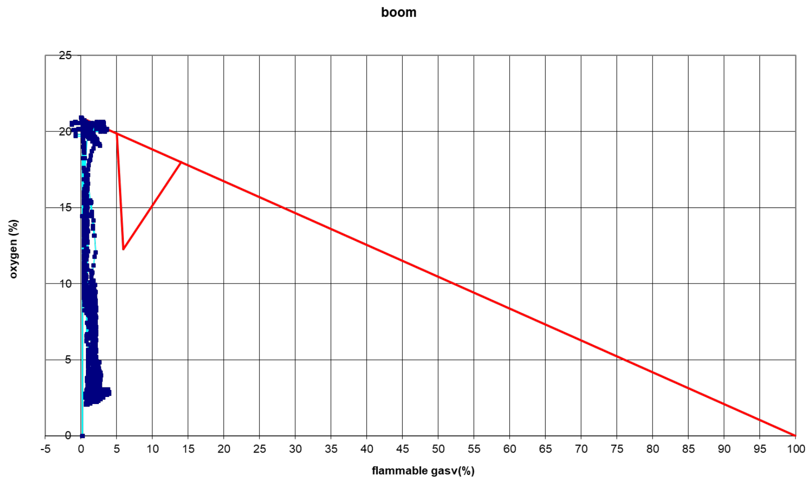

Figure 10: Same data depicted on the traditional Coward Triangle

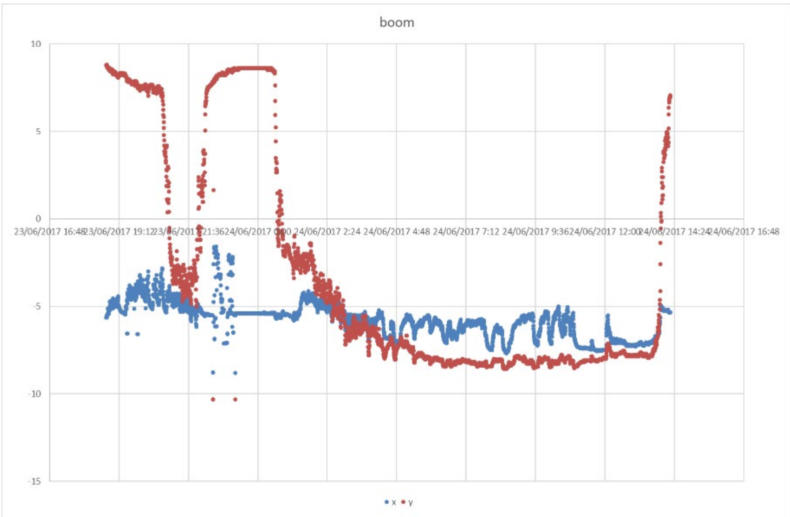

Figure 11: Highwall mining data on Ellicott X Y diagram

Another example would be the explosions at Moura No.2 mine in 1994. The traditional Ellicott X Y is depicted below as well as the new explosibility diagram (Figures 12 to 13\5). In the cases of the coward triangle and the Ellicott diagram, had an observer been watching them develop over time then it would have been clear that the atmosphere would become explosive. It would have been more difficult to gauge the rate of movement. The Ellicott XY diagram allows easy prediction of when the explosive atmosphere would occur (both X and Y need to be positive), however it is not possible to easily estimate what percentage of the LEL was occurring and thus what TARP would be triggered. The new diagram clearly demonstrates both the rate of progress and also what percentage of the LEL is occurring as the atmosphere progresses from essentially fresh air toward the LEL (yellow dots). The new diagram also clearly demonstrates that, initially at the monitoring point, there was a fuel rich atmosphere (the brown dots) which mixed with air over time and actually formed an explosive atmosphere (the red dots) after the first explosion and slowly dissipated through air inflow before the second explosion occurred. The known monitoring location, was sampling from a different location to the 512 panel seal.

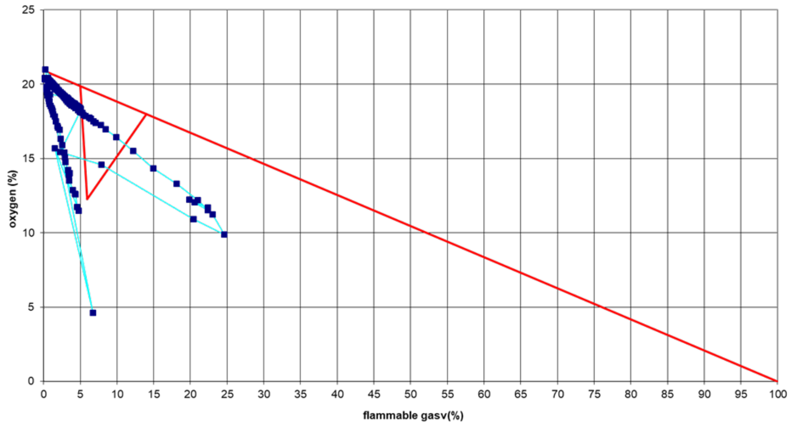

Figure 12. 512 seal data on Coward Triangle

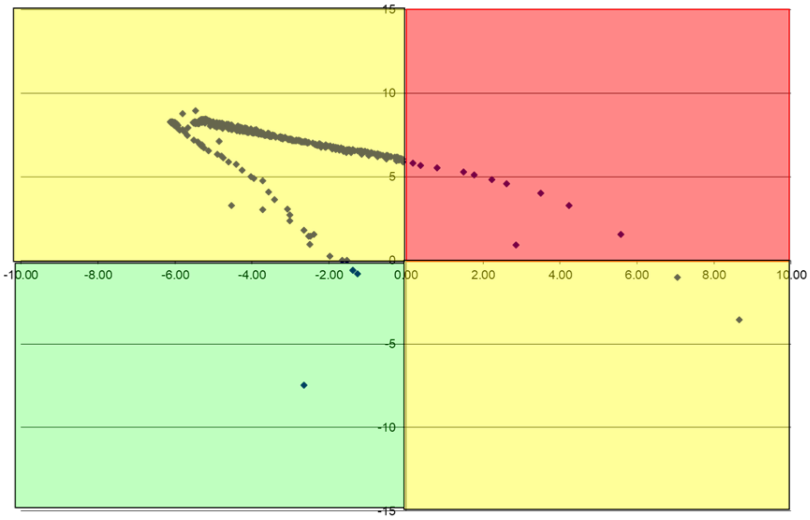

Figure 13. 512 seal data on Ellicott diagram

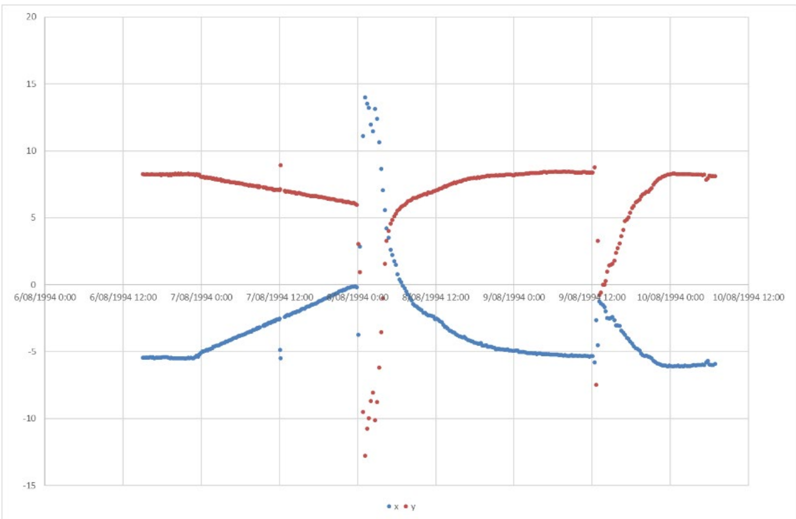

Figure 14: Ellicott XY plot of 512 data

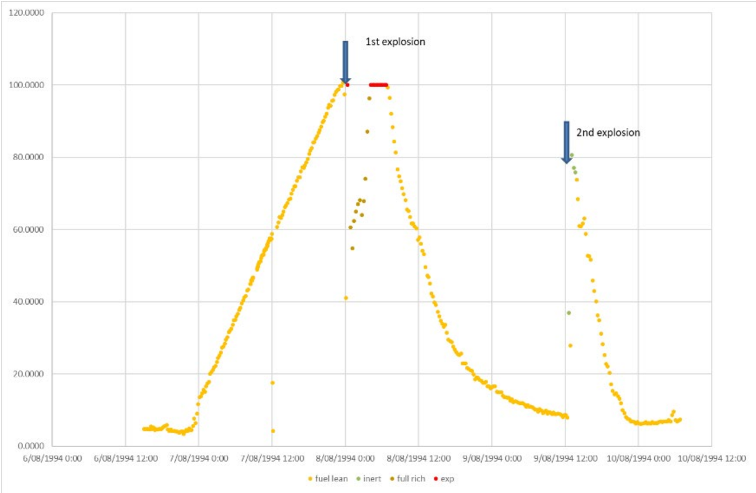

Figure 15: 512 data on new explosibility diagram

CONCLUSIONS

Traditional explosibility diagrams have limitations when used to trend the potential for explosion over time. A new diagram has been developed in an effort to overcome those issues. It is able to plot the percentage of the explosibility (LEL or UEL) from any of the zones as a function of time, giving better perception of the explosibility risk. This diagram should find application in emergency situations as well as when working with atmospheres that are fuel rich.

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