Mine Atmosphere Interpretation Tools

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INTERPRETATION OF RESULTS

The action taken will be governed by our understanding of the results provided by the sampling process.

The key questions to be answered are:

- Do we have confidence in the integrity of the results?
- What do the results really tell us?
- Are they normal or abnormal?
- Are we confident that we know what "normal" really means?
- Has there been any change in any environmental factor that may cause an abnormal result?
- Is the change from normal of sufficient magnitude to require action on our part?

Environmental factors that may cause an abnormal result may include, but not necessarily be limited to:

- Diurnal barometric variation
- Rapid barometric pressure drop due to storms
- A change in the ventilation quantity at the sampling point
- Ambient temperature and humidity fluctuations
- Exhaust gases from diesel equipment operated upstream of the sampling point.

Or an abnormal result may be the result of:

- Flammable and/or noxious gas released due to ground movement, major falls or collapsed seals.
- Gases produced from smouldering coal adjacent to overheated equipment, fixed installations or conveyor belts.
- Above ambient temperature oxidation of coal.

This is by no means an exhaustive list, but it does give some indication of the many factors which must be considered.

Interpretation of Gas Analysis Results

What is Normal?

- Develop a clear understanding of the normal state of the mine atmosphere
- Remember, it is not the presence of flammable or noxious gases that is most important. You need to know:
  - the level or percentage of the gas present
  - the nature, type and characteristics of the gases present
  - the state of the ventilation
  - if the presence of the gas/gases poses a hazard that must be controlled.

What is Abnormal

- Any condition or state which has caused a deviation from normal background gas levels detected in the mine or place.
  - Experience has shown us that it is very difficult to nominate a specific Trigger Alarm Level for a particular gas without good reliable historical data because we have observed different background gas levels within the same seam and in the longer longwall panels, within the same panel.
  - To this end we have to be guided by legislation which sets maximum levels.

Abnormal State due to Environmental Factors

- Diurnal (twice daily) barometric variations
- Rapid barometric pressure drops due to storms
- Change in ventilation quantity
- Ambient temperature and humidity fluctuations
- Exhaust gases from diesel equipment, operated outbye or in the airways on the upstream side of the sample point

Abnormal State due to Other Causes

- Major falls, ground movement, floor heave, outbursts, equipment fires or collapsed seals
- Gases produced by overheated equipment or installations, conveyor belts and the like
- Above ambient temperature oxidation of coal

DO NOT ASSUME THAT AN ABNORMAL RESULT IS CAUSED BY ONE OR MORE OF THE ABOVE FACTORS. INVESTIGATE AND PROVE THAT IT IS NOT.

Immediate Action

- An abnormal result may trigger immediate action such as:
  - Isolation of Electric Power
  - Shut down of Diesel Equipment
  - Repair of Ventilation Appliances
  - Increase of Air Flow
  - Withdrawal of persons

INTERPRETATION TOOLS

Prime Objective

- To recognise the subtle changes in the mine atmosphere that may in fact be the early warning signs of impending disaster.
- To promptly detect these subtle changes and take appropriate action to control the event and thereby reduce the risk.

CAUTION

- Consider the accuracy of the sample, the methods used to collect it, the detectors used and the analysis process.
- When low levels of flammable or noxious gas are present or the oxygen deficiency is very low the results of many ratios or other interpretation tools used may be questionable.
- When the deviation in the trend of any of the interpretation tools or ratios used occurs, firstly look for an obvious cause, e.g.
  - Barometric Pressure
  - Quantity of Airflow
  - Operation of Equipment
  - Temperature and Humidity

Interpretation Tools for Monitoring Point, Bag or Bulk Samples taken for full analysis.

We would recommend that the following indicators be considered conjointly:

- Barometric Pressure
- Sample Air Flow in M^3/sec
- Wet Bulb and Dry Bulb Temperature, Surface and Sample Point
- Total Impurities or the Total Air Free Gas present
- Carbon Monoxide Make
- CO/CO2 Ratio
- Oxygen Deficiency
- Air Free Gas Produced in Ltrs/Min
- Grahams Ratio
- Composition of Air Free Gas

Don't rely on one indicator. Use every tool available to help you understand just what the analysis results are really telling you.

Most importantly you need the input from the sampler and the benefits delivered by their sense of smell, taste, touch and feeling.

Barometric Pressure

- When Barometric Pressure falls, gases in the coal seam or a sealed area will expand and may flow or leak out into mine airways.
- A high or rising Barometer may hold or force gases back into the Seam, Goaf or Sealed Workings
- Exercise caution when there is a sudden fall due to storms or some other effect. This may cause gases to flow into the workings very rapidly.
- A slow gradual fall will cause a slow gradual increase of flammable or noxious gases in the workings.
- When the Barometric Pressure is High and appears stationary, it is very likely that it will fall in the near future.
- It is not unusual for the gases in the Seam, Goaf or Sealed area to expand before the Barometric Pressure Drop has been actually observed.

Sample Air Flow

- The quantity of the air flow at the sample point is vital for the determination of Gas Make.
- The actual make in Litres per Minute of a number of flammable and noxious gases will provide valuable information for the Interpretation Process.

- If there has been a change in the level of gas detected at a sample point then is this due to a change in quantity of air flow at the sample point?
- Don't assume that the quantity of air flowing in a roadway is the same as it was the previous shift, day, week or month. It rarely will be the same.
- We need to recognise that if there has been any evidence of heating that could have altered the air temperature upstream of the sample point then the quantity of air flowing in the roadway will most definitely have changed.
- When sampling near a goaf edge, look for the warmest air stream as this will be the airflow carrying the most impurities. Usually, if one moves across the goafedge with the hand outstretched the warmest air stream is fairly easy to detect.

Sample Point Temperature

- Experience has shown that the Wet and Dry Bulb Temperature at a well established Monitoring Point underground, has little if any relationship to the temperature on the surface of the mine.
- This would suggest that a change in the normal Wet and Dry Bulb Temperatures at the Sample Point may be attributed to:
  - Change in Air Quantity
  - Equipment activity
  - Physical or Chemical Activity inbye of the Sample Point
- **Logically, the first sign of a heating will be an increase in temperature in the return air current**. Ambient temperature in the return of a working panel will normally be equal to 29 to 31oC (coal & rock temperature) and probably 2 to 3oC due to operation of active longwall. Carbon Monoxide is produced at approximately 40 to 50oC (depending on the coal). Air moving across a site where oxidation is beginning to occur will be heated above the ambient temperature therefore creating a window of opportunity where an effective sample of the temperature will highlight the event prior to the production of CO.

Refer to Table 1.

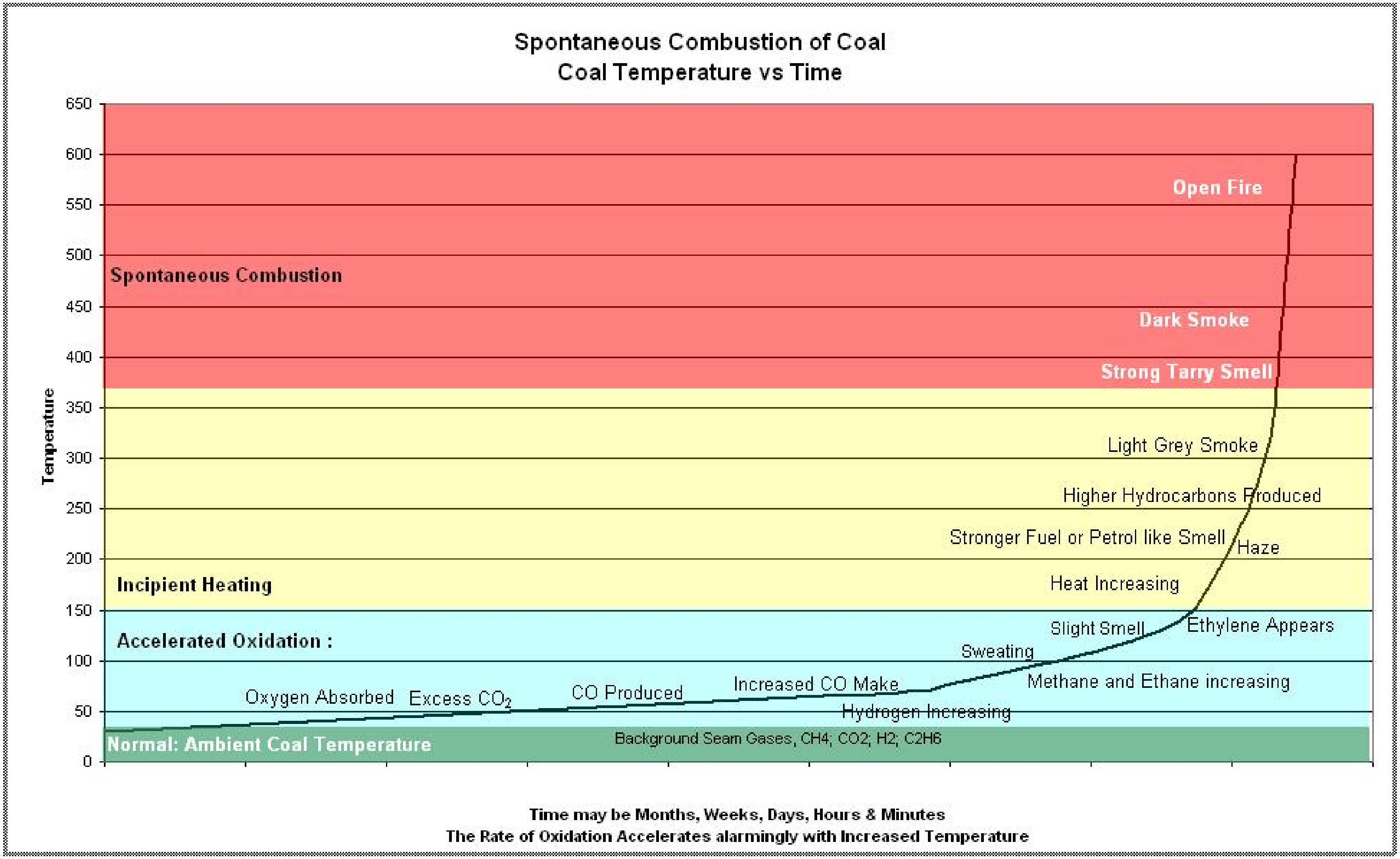
Spontaneous Combustion of Coal
Coal Temperature vs Time
Temperature
650
600
550
500
450
400
350
300
250
200
150
100
50
0
Open Fire
Spontaneous Combustion
Dark Smoke
Strong Tarry Smell
Light Grey Smoke
Higher Hydrocarbons Produced
Stronger Fuel or Petrol like Smell
Haze
Incipient Heating
Heat Increasing
Accelerated Oxidation :
Slight Smell
Ethylene Appears
Sweating
Methane and Ethane increasing
Oxygen Absorbed
Excess CO2
CO Produced
Increased CO Make
Hydrogen Increasing
Background Seam Gases, CH4; CO2; H2; C2H6
Normal: Ambient Coal Temperature
Time may be Months, Weeks, Days, Hours & Minutes
The Rate of Oxidation Accelerates alarmingly with Increased Temperature

Table 1

Total Impurities or Air Free Gas

- This refers to the Total Impurities present in the Mine Atmosphere at the Sample Point
- The Impurities or Air Free Gas present in Fresh Air is Zero, therefore any increase in this result indicates a deterioration of the Mine Atmosphere
- Some Researchers suggest that an Air Free Gas Content of up to 2.0% is normal and that the results of many ratios will be questionable and of little value in atmospheres which contain less than 2.0% impurities.
- The Total Impurities or Air Free Gas present at the monitoring point is one of the best indicators of the overall health of the mine atmosphere.
- Air Free Gas Content is determined in the following manner:
  - Sum of the Gases Present by analysis normalised to 100.00%
  - Assume Sample Oxygen Content =20.5%

    Air associated with sample oxygen is:

    (20.5 x 3.776) + Sample Oxygen + Carbon Dioxide in Fresh Air

    (20.5 x 3.776) + 20.5 + 0.03 = 97.94%
- Alternative method, Sample Oxygen x 4.776 + 0.03

  = (20.5 x 4.776) + 0.03 = 97.94%

  Therefore Total Impurities or Total Air Free Gas present = 2.06%
- The Mine Atmosphere at the Sample Point contains, for this example:

  97.94% Air

  2.06% Total Air Free Gas

NOTE:

Two constants will be used for the purpose of these interpretation tools and there may be some debate about their absolute accuracy, however, it must be remembered that any inaccuracy will be small and constant and that we are really looking for changes or a deviation in a trend line, rather than the absolute accuracy of a single result.

Constants Used: 3.776

0.265

For the purpose of these Interpretation Tools, Normal Fresh Air is taken as:

Nitrogen plus other inerts	= 79.04%
Oxygen	= 20.93%
Carbon Dioxide	= 0.03%
Total	= 100%

Therefore for every one Volume of Oxygen in Fresh Air, there is:

$$\frac{79.4}{20.93} = 3.776 \text{ Volumes of Nitrogen}$$

Conversely for every one Volume of Nitrogen in Fresh Air there is:

$$\frac{20.93}{79.04} = 0.265 \text{ Volumes of Oxygen}$$

The next logical step is to determine the actual composition of the impurities or Air Free Gas and to Trend the results over time.

This trend assists persons conducting interpretation of the atmosphere factor in the variations between the skills and knowledge of the persons taking samples and the location of the sample point which may be influenced by hanging goaf, goaf flushing, fully caved goaf and primarily varying dilution factors.

You will note that the majority of the Air Free Gas will be excess Nitrogen and you will be more interested in the behaviour of Air Free;

- CO_2
- CO
- CH_4
- Hydrogen
- Ethane

You are looking for any abnormal change or unexplained increase on an Air Free basis in any one or combination of the above gases. Note: if there is no real abnormal activity, the Air Free Trend will be a relatively flat trend.

The following table, Table 2, assists persons collecting samples to understand first hand the quality of the air they are breathing, and sampling. The process is:

- On the Table, identify your O2 % reading from your handheld detector. (rounded up) e.g. 20.3% O2
- Note the impurities, or Air Free Gas, %. E.g. 3.02%
- On the Table, identify your sampled gas (CO) reading from your handheld detector e.g. 6ppm.
- Note the Air Free Gas by lining up the 3.02% and 6ppm. This result from the example is 199ppm Air Free Co. **What does this tell you?**

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Air Free Gas Table

Sampled Gas in ppm																		
Oxygen %	20.7	20.6	20.5	20.4	20.3	20.2	20.1	20	19.8	19.6	19.4	19.2	19.0	18.8	18.6	18.4	18.2	18.0
Impurities %	1.11	1.58	2.06	2.54	3.02	3.49	3.97	4.45	5.41	6.36	7.32	8.27	9.23	10.18	11.14	12.09	13.05	14.00
2	181	126	97	79	66	57	50	45	37	31	27	24	22	20	18	17	15	14
3	271	189	145	118	99	86	76	67	56	47	41	36	33	29	27	25	23	21
4	361	252	194	158	133	114	101	90	74	63	55	48	43	39	36	33	31	29
5	452	316	242	197	166	143	126	112	93	79	68	60	54	49	45	41	38	36
6	542	379	291	236	199	172	151	135	111	94	82	73	65	59	54	50	46	43
7	632	442	339	276	232	200	176	157	130	110	96	85	76	69	63	58	54	50
8	723	505	388	315	265	229	201	180	148	126	109	97	87	79	72	66	61	57
9	813	568	436	354	298	258	227	202	167	142	123	109	98	88	81	74	69	64
10	904	631	485	394	331	286	252	225	185	157	137	121	108	98	90	83	77	71
11	994	694	533	433	365	315	277	247	204	173	150	133	119	108	99	91	84	79
12	1084	757	582	473	398	343	302	270	222	189	164	145	130	118	108	99	92	86
13	1175	820	630	512	431	372	327	292	241	204	178	157	141	128	117	108	100	93
14	1265	884	679	551	464	401	352	315	259	220	191	169	152	138	126	116	107	100
15	1355	947	727	591	497	429	378	337	278	236	205	181	163	147	135	124	115	107
16	1446	1010	776	630	530	458	403	360	296	252	219	193	173	157	144	132	123	114
18	1626	1136	873	709	597	515	453	404	333	283	246	218	195	177	162	149	138	129
20	1807	1262	970	788	663	572	503	449	370	314	273	242	217	196	180	165	153	143
22	1988	1389	1067	866	729	630	554	494	407	346	301	266	238	216	198	182	169	157
24	2168	1515	1164	945	795	687	604	539	444	377	328	290	260	236	216	198	184	171
26	2349	1641	1261	1024	862	744	655	584	481	409	355	314	282	255	233	215	199	186

Air Free Gas in ppm

Table 2

Carbon Monoxide Make

- The production or make of Carbon Monoxide will increase with increased temperatures or Accelerated Oxidation of Coal.
- Carbon Monoxide Make may be calculated by any one of the following:

  CO make in Litres per Minute
  = CO x Air Flow x Constant K

  CO in ppm and Airflow in m^3/second
  then K = 0.06

  CO in Percent and Airflow in m^3/second
  then K = 600

- A stable atmosphere will deliver a flat trend line with some minor fluctuations and over time it could be expected to rise slowly.
- Anomalous peaks may be caused by the operation of Diesel Equipment in the air split however, the trend should return to normal when there are no diesels operating.
- Note the magnitude and frequency of CO Make Peaks and an upward trend or an increase in the frequency of these peaks is an indication of some physical or chemical activity inbye of the monitor point.
- A definite upward trend of greater than 7 litres per minute above normal background level, which cannot be attributed to diesel vehicle activity, must be investigated.

Our research indicates that carbon monoxide is produced fairly rapidly on the exposure of fresh coal and that the level of CO detected increases with the amount of coal exposed.

This production of CO does not appear to be linear or cumulative in the strict sense but it does appear that the CO level increases initially as the coal is exposed and then decreases almost as rapidly if no additional coal is exposed.

The net result is that CO levels may fluctuate wildly in different seams and from different areas in the same seam and with the volume of coal exposed or tonnes of coal produced and we are therefore convinced that by itself CO Make is not a reliable indicator of an incipient heating or the initial stages of accelerated oxidation of coal.

Some researchers believe that to get a true indication of the CO Make we need to determine the level of CO in the intake airway first and take this away from the CO level detected in the return airway. This is only valid when the samples collected in the intake and return sides are actually collected from the same volume of mine air as it passes the two sample points.

When we consider the velocity of the air across the average production panel and the overall accuracy of the analytical process, we can appreciate that there are major obstacles to overcome before this can be achieved in an operating mine.

It is far more important to have realistic Trigger Levels and Trigger Action Response Plans that are invoked when a Trigger Level is verified.

CO/CO_2 Ratio

- USBM Engineers modification of Rhead and Wheeler 1910
- This Ratio will increase as the Temperature of the coal increases and then decrease rapidly as the coal gets hotter.
- Background value will be affected by higher levels of seam gas Carbon Dioxide
- Investigate upward trend and recognise that the actual value or result calculated may vary widely at monitoring points located in the same ventilating circuit.
- Changes to the Trend are important, not the value.
- There appears to be little if any correlation to the values arrived at by Firegas Determinations in a laboratory as the values actually determined outbye of known low grade heatings were lower than predicted by Firegas testing.
- The Ratio may be calculated in the following manner:
  - Sample CO/(Sample CO2-0.03)
  - A more reliable method is to remove the seam gas carbon dioxide as well and use the remainder as the divisor.

CARE MUST BE EXERCISED IF THE MINE ATMOSPHERE CONTAINS HIGH LEVELS OF CARBON DIOXIDE

Oxygen Deficiency

- The oxidation process will consume or absorb oxygen from the mine atmosphere.
- The trend increases rapidly when analysis results from a known heating are added to the range.
- Oxygen Deficiency may be calculated in the following manner:
  - Sample N2 x 0.265 - Sample Oxygen
- Oxygen deficiencies below 0.2% may result in inaccurate determinations of Graham's Ratio.

Air Free Gas Produced in Litres/Minute

- A useful tool for measuring and trending the Total Quantity of the Impurities present in the mine atmosphere.
- The trend may rise and fall due to Barometric Pressure effects and should it increase rapidly then the cause must be investigated immediately.
- Air Free Gas Produced in Litres per Minute =
  - Total Impurities % x Air Flow in M^3/sec x 600

Graham's Ratio

- This Ratio will increase if there is any activity associated with the production of Carbon Monoxide and the Absorption of Oxygen
- Oxygen deficiency must be greater than 0.2 percent
- This Ratio is unsuitable in zones where there are accumulations of Blackdamp or where Inertisation has or is being used.
- Our investigations strongly suggest that this Ratio should be Trended for all samples containing Carbon Monoxide where the Oxygen Deficiency is greater than 0.2 percent.
- We firmly believe that these low values of less than 0.25 may be vitally important for the early detection of the subtle changes associated with accelerated oxidation.
- Grahams Ratio is calculated by taking the amount of Carbon Monoxide Produced, expressed in percent * 100 and divide this by the calculated Oxygen Deficiency.

  - For example: 60ppm CO with an Oxygen Deficiency of 1.5%
    Therefore 0.006 * 100 / 1.5 = Grahams Ratio of 0.4

Reference Material and suggested reading:

- A Manual on Mines Rescue and Gas Detection, J. Strang and P. Mackenzie-Wood.
- Spontaneous Combustion in Australian Underground Coal Mines, SIMTARS.
- Mine Fires in Australian Underground Coal Mines, SIMTARS.
- End of Grant Report NERDDP Project 1463 Investigation of Bowen Basin Coal Mine Fire Gas Analysis Parameters, Dr D. Cliff, S. Bell, T. O'Beirne.
- Applying Atmospheric Status Equations to Data Collected From a Sealed Mine Postfire Atmosphere, R. Timko and L. Derick United States Bureau of Mines.