

THE BENEFITS OF KINETIC TESTWORK USING OXYGEN CONSUMPTION TECHNIQUES AND IMPLICATIONS FOR THE MANAGEMENT OF SULFIDIC MATERIALS

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ABSTRACT

A key component of understanding and managing the acid metalliferous drainage (AMD) risk associated with sulfidic materials involves quantifying their rate of oxidation. This rate is directly proportional to the pollution generation rate from sulfidic materials. It is now well understood that the sulfide oxidation rates are strongly influenced by a range of factors including grain size, mineralogy, temperature, humidity, bacterial activity, oxygen concentration, sulfide concentration and the use of alkaline amendments and surface passive reactions. Furthermore, at a specific grain size, it is clear that substantial variation in oxidation rates is related to variable moisture contents, which strongly influence oxygen diffusion. While some kinetic testwork techniques permit quantitative assessment of the influence of some of these variables, only oxygen consumption tests enable accurate and independent determination of sulfide oxidation rates as a function of all of these variables.

An apparatus that measures changes in the volumetric headspace above a sample in a sealed vessel at ambient temperature and pressure permits accurate and direct measurement of oxygen consumption (sulfide oxidation) rates under controlled conditions. An internal carbon dioxide absorbent permits independent determination of carbon oxidation rates, or carbon dioxide release rates from the dissolution of carbonate minerals.

Key advantages of this oxygen consumption (OxCon) testwork are that it is low cost, fast to complete (eg. 1 to 6 weeks depending on sulfide content), provides a high degree of accuracy, can simulate the full range of oxygen concentrations, it is not influenced by sulfate precipitation or dissolution reactions, permits sensitive control over a broad range of variables (moisture content in particular) and can provide typical leachate water chemistry after testwork is complete.

Sulfide oxidation rate data have been acquired for a range of materials from acid sulfate soils (ASS) to mine materials as a function of grain size, ambient oxygen concentration, moisture content and morphology. These data are presented. Sulfide oxidation rates ranged from 0.43 wt% pyrite oxidised per year (ie. 4.52×10^{-11} kg (O₂) kg (material)⁻¹ s⁻¹ for a sample containing 17.7 wt.% S) to 1.24 wt% pyrite oxidised per day (ie. 1.18×10^{-12} kg (O₂) kg(material)⁻¹ s⁻¹ for a sample containing 0.16 wt.% S). The implications of this data are discussed to highlight important management measures.

1.0 INTRODUCTION

The exposure of sulfide minerals such as pyrite and marcasite (FeS_2) to oxygen as a result of mining activities, large-scale earthworks, dewatering operations often associated with agriculture or uncontrolled drying of sulfidic sediments can result in acid and metalliferous drainage (AMD; also traditionally referred to as 'Acid Mine Drainage' or 'Acid Rock Drainage'). AMD has resulted in ongoing environmental problems in the mining industry worldwide, compounded by the rapidly growing trend toward large tonnage open-cut mines over the past 30 to 40 years (DITR 2007). Climate change and over allocation of dwindling water resources have also increased the risk of exposure of sulfidic soils (ASS; acid sulfate soils) in wetlands and agricultural environments.

The management of AMD can be achieved by prevention, control or treatment. Due to the high cost and limited success of control and treatment, prevention is the favoured management strategy (DITR 2007). A key aspect of preventative action is predicting the risk associated with various geologic materials. Prediction requires characterisation of the sulfidic materials using static and kinetic geochemical tests. Static tests assess the maximum potential of a sample to generate acidity based on its total sulfide content. Such tests, however, do not consider the rate or duration of acidity generation. In addition, AMD generation is affected by many variables that are not considered in static tests such as the availability of reactive pyrite within a rock matrix (Nicholson 1994) and the supply of oxygen to the reaction sites (Ritchie 1994). For these reasons, kinetic geochemical tests are carried out to estimate the rate at which AMD is generated and the longevity of issue.

Kinetic tests can be performed in the laboratory or the field. Commonly used geochemical kinetic tests include humidity cells, column leach tests, field-scale test piles; and field and laboratory oxygen consumption tests. Humidity cells are laboratory apparatus in which crushed samples are subjected to successive exposure to moist air, dry air and water flushing. In this manner, an artificial climate is created that accelerates the rate of sulfide oxidation. Sulfate release is measured during flushing cycles over 3-12 months and data interpreted to estimate the acidity generation characteristics of geologic materials. Significant errors may occur in the interpretation of this data, especially in colder climates where the difference between the actual climate and the induced climate in the humidity cell is significant (Comarmond 1997).

Column leach tests can be laboratory or field-based and involve the controlled or natural irrigation of sulfidic materials within a container (eg. PVC column). There is great variability in the design of column tests based on budget, site conditions and research requirements (Comarmond 1997). The column test is considered by some to better replicate site conditions than humidity cells by accounting for site temperatures and rainfall regime, as well as actual particle size distributions. Column leach tests can also be accelerated with artificial wetting and drying cycles. Sulfate release is measured during flushing cycles over extended periods (eg. 6-24 months) and data interpreted to estimate acidity generation.

A larger form of site based experiment is a test pile (eg. Taylor et al. 2009), which provides a better model of the AMD behavior of a waste rock pile and the water quality produced. These involve large volumes of rock placed on a membrane so that the leachate from the test pile may

be collected and analysed. These piles may also incorporate oxygen transport as a limiting factor in the production of AMD. As a general rule, an increase in the scale of the test pile leads to a decrease in the pyrite oxidation rate estimate (Sracek et al. 2006).

Oxidation rates estimated from kinetic testwork techniques that rely on sulfate release rates can be underestimated if sulfate precipitates in the column or test pile (eg. gypsum, schertmannite, jarosite) or overestimated by progressively dissolution of residual sulfate or sulfate-bearing secondary minerals if they are present in the sample prior to the commencement of testwork.

Oxygen consumption experiments can also be field or laboratory scale. The measurement of oxygen concentrations over time either in the field or laboratory can be used to provide estimates of the pollution generation rate of a material. Field based experiments include measurement of oxygen concentration profiles over time (ANSTO 1997; Cook et al. 2004; Ward et al. 2004a, 2004b; Scarek et al. 2006) or installation of a chamber onto sulfidic material to isolate gas in the chamber headspace, followed by subsequent measurement of oxygen concentration over time (Kempton, 2009).

Laboratory based oxygen consumption testwork generally consists of a sealed sample chamber containing sulfidic material, and subsequent measurement of gas concentrations in the headspace inside the chamber over time to determine the oxygen consumption rate.

Oxygen consumption techniques have many advantages when compared with other kinetic test techniques. These include:

- Rapid determination of oxidation rates: ANSTO claims 12 hours, others from 2 days to 2 weeks (Anderson et al. 1999; Bennett et al. 2005; Eidsa et al. 1997; Hollings et al. 2001).
- Many simultaneous or sequential runs are possible, enabling statistical analysis of results (Anderson et al. 1999; Bennett et al. 2005; Hollings et al. 2001).
- Ability to test many variables including moisture content (directly related to oxygen diffusion), oxygen concentration, particle size distribution, carbonate content, metamorphic grade, sulfide content, sulfide mineralogy, bacterial inoculation, and temperature (Anderson et al. 1999; Hollings et al. 2001).
- Oxygen consumption can be directly related to sulfide oxidation. In this way, oxygen consumption techniques are more accurate than assumptions based on leachate sulfate fluxes. Sulfate may be release from unrelated secondary minerals present in sample (leading to overestimation of the oxidation rate) or may precipitate following neutralisation reactions (eg. gypsum) leading to underestimation of the oxidation rate.
- Oxygen consumption testwork only requires small sample sizes, and technique can be scaled up/down or customized with relative ease.
- There is no need for expensive laboratory analyses, only initial ABA (acid-base accounting) is required. Leachate water chemistry can be conducted at the conclusion of an oxygen consumption test to compare sulfide oxidation rates based on oxygen consumption and sulfate release during leaching (Hollings et al. 2001).

This paper reviews published information relating to oxygen consumption techniques and discusses the many benefits of oxygen consumption testwork. It also describes a new, inexpensive laboratory technique based on the oxygen consumption method and provides testwork data. Management implications for mines and acid sulfate soils are also presented.

2.0 OXYGEN CONSUMPTION TECHNIQUES

2.1 Overview of Existing Oxygen Consumption Techniques

Oxygen consumption testwork requires a gas impermeable chamber for storing a sulfidic sample (Bennett et al. 2005; Anderson et al. 1999; Eidsa et al. 1997; Scarek et al. 2006; Hollings et al. 2001; Jerz et al. 2004; Elberling 2005; Andersen et al. 2001). Over time, gas concentrations can be measured by, a) gas chromatography (Elberling 2005; Andersen et al. 2001); b) direct measurement inside the vessel using electrochemical gas sensors (Anderson et al. 1999; Hollings et al. 2001; Bennett et al. 2005; Eidsa 1997) or c) by measurement of pressure changes in the vessel (Jerz et al. 2004) assuming all pressure change is attributed to oxygen consumption.

Carbon dioxide generated from neutralisation reactions or bacterial oxidation of organic carbon (in samples containing organic carbon such as acid sulfate soil material) can also be measured using carbon dioxide sensors (Eidsa et al. 1997; ANSTO 1997) or by gas chromatography. Carbon dioxide generation rates can then be used to readjust oxygen consumption rates, and can assist in identifying the acid neutralisation capacity or bacterial activity of a sample (Hollings et al. 2001). Leachate water quality can be obtained after testing, allowing comparison between oxidation rates based on sulfate release and oxidation rates based on oxygen consumption (Hollings et al. 2001).

Test times varied in the literature, with most testwork conducted over 0.5-5 days (Elberling et al. 2005; Hollings et al. 2001; Anderson et al. 1999; Bennett et al. 2004; Sracek et al. 2006). However, some experiments lasted for 2-8 weeks (Eidsa et al. 1997; Andersen et al. 2001).

2.2 New Approach to Oxygen Consumption Testwork

Oxygen Consumption testwork is a geochemical kinetic testwork methodology that measures oxygen consumption to determine the pyrite oxidation rate (and pollution generation rate) of a sample. The new OxCon (oxygen consumption) test procedure developed by the authors is based on similar oxygen consumption test methods developed and used by other researchers (eg. ANSTO).

Prior to testing, representative samples of sulfidic material are analysed for the following parameters:

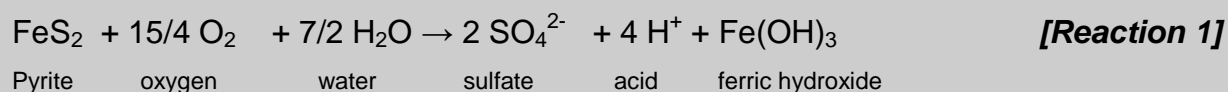
- Moisture content (wt.%);

- Total sulfur (wt.% S);
- Acid Neutralisation Capacity (kg H₂SO₄ / t);
- Net Acid Generation (NAG_{4.5} and NAG_{7.0}) and pH after oxidation (NAG_{pH});
- Total Organic Carbon (TOC, optional for acid sulfate soils and coal mine samples);
- Particle size distribution (optional);
- Major and trace element geochemistry (optional).

The OxCon apparatus (shown in Plates 1 and 2) operates by permitting a known mass of sulfide bearing material to react with a known volume of oxygen inside a sealed vessel. Once testwork is instigated, oxygen consumption proceeds via sulfide oxidation (see Reaction 1) causing the internal pressure of the system to decrease. For the system to maintain equilibrium with the atmosphere, fluid is drawn from the fluid reservoir into the displacement chamber. The mass of fluid transferred into a displacement chamber is proportional to the volume of oxygen consumed. These two parameters are related via Boyle's Law, and with continuous measurement of ambient temperature, barometric pressure and displacement chamber mass changes over time, it is possible to calculate an oxygen consumption rate (eg. mol/day/mass of sulfide).

The measured oxygen consumption rate is assumed to be proportional to the mass of pyrite in the sample and is converted into a pyrite oxidation rate using the stoichiometry in Reaction 1 (ie. 3.75 moles of oxygen are consumed to oxidise 1 mole of pyrite). This assumes that all sulfur present is in the form of reactive pyrite and that Reaction 1 is driven to completion. The pyrite oxidation rate is reported as a weight percent of pyrite exposed to atmospheric oxygen that will be oxidised to ferric hydroxide (Fe(OH)₃) and sulfuric acid (H₂SO₄) per year. This study reports sulfide oxidation rate results in units of weight percent of pyrite (exposed to atmospheric oxygen) that is converted to sulfuric acid per year. (wt.% FeS₂ converted / year). This is a convenient unit that facilitates the rapid determination of acidity generation data for individual waste rock piles or entire mine sites.

Alternatively, OxCon data can be reported as intrinsic sulfide oxidation rates (IOR). IOR's are reported in units of kilograms of oxygen consumed per kilogram of material per second (kg O₂ / kg (material) / sec). As these units do not normalize the oxidation rate to unit sulfide content, it is difficult to apply them broadly to the behaviour of a waste rock pile. Other workers use units of kilograms of sulfur oxidised per tonne of material per year (kg S / tonne (material) / year), and these units are also difficult to apply broadly to a site.



With knowledge of the pyrite oxidation rate of a sulfidic material (normalised to the sulfur content) and the mass and average sulfur content of the material, it is possible to estimate the annual acidity generation rate of a material ($\text{kg H}_2\text{SO}_4 / \text{tonne (material) / year}$), regardless of its sulfide content. For example; if 1.0 million tonnes of waste rock with an average pyrite content of 3 wt.% FeS_2 and a pyrite oxidation rate of 0.5 wt.% FeS_2 per year (ie. 0.5 weight percent of all FeS_2 exposed to atmospheric oxygen that will convert to sulfuric acid per year) were exposed to atmospheric oxygen, the estimated acidity generation rate would be approximately 150 t H_2SO_4 per year, or 0.15 $\text{kg H}_2\text{SO}_4$ per tonne of rock per year.

Pyrite oxidation rates obtained in the laboratory may vary considerably to those achieved in the environment due to a number of factors including: moisture content (this can limit oxygen diffusion to reaction sites); particle size distribution (related to the surface area available to react with oxygen); sulfide mineralogy; oxygen concentration; and temperature. The OxCon procedure can be used to develop relationships between the pyrite oxidation rate and one or more of these variables to enable more reliable estimates of real-world acidity generation rates. For example, pyrite oxidation rates can be determined for waste rock samples of various particle size fractions. These rates can be used with knowledge of the actual particle size distribution of waste rock to more reliably estimate annual acidity generation rates.



Plate 1: OxCon apparatus vessels including (from left to right) sample chamber, displacement chamber and fluid reservoir.



Plate 2: OxCon apparatus depicted with data logger, temperature transmitter and power supply.

Once OxCon testwork is completed, the sample can be flushed with deionized water and analysed for:

- pH and electrical conductivity (EC);

- Acidity;
- Major ions and dissolved metal concentrations.

The leachate chemistry can be used to provide indicative information on likely water quality and key elements of concern; determine trace element leach rates (using trace element geochemistry results); and to independently estimate sulfide oxidation rates using measured sulfate and acidity released during leaching. Comparisons between sulfide oxidation rates measured from oxygen consumption and sulfate leach rates can also provide important information on the contribution of secondary mineral dissolution to acidity generation.

Carbon dioxide generated a) as a result of bacterial oxidation of organic carbon (eg. for acid sulfate soils or coal samples) or b) from carbonate neutralisation reactions, can be measured using a carbon dioxide absorbent located inside the sample chamber during oxygen consumption testing. The mass change in absorbent can be used to estimate the rate of organic carbon oxidation or to estimate the extent of neutralisation that occurred during testing. The effects of CO₂ gas release during OxCon testwork is routinely quantitatively accounted for in the calculation of FeS₂ oxidation rates.

Oxygen consumption techniques have many advantages when compared with other kinetic test techniques such as column leach tests and humidity cells. These include:

- Rapid determination of oxidation rates (usually 1-6 weeks).
- Lower cost, relative to other techniques.
- Greater accuracy. Measurement of oxygen consumption is more accurate than inferences based on measurement of leachate sulfate fluxes (such as in column leach tests and humidity cells). Sulfate may be released from unrelated secondary minerals present in sample leading to an overestimate of the pyrite oxidation rate, or may precipitate as a secondary sulfate mineral leading to an underestimate of the pyrite oxidation rate.
- Multiple simultaneous and sequential experiments are easily conducted, enabling repeat runs for greater confidence or for testing different variables including moisture content (directly related to oxygen diffusion); oxygen concentration; particle size distribution; carbonate content; metamorphic grade; sulfide content; sulfide mineralogy; bacterial inoculation; and temperature.
- Small sample size (also, technique can be scaled up/down or customized with relative ease).
- No need for multiple laboratory analyses during testwork, only initial ABA required, with leachate water chemistry being optional.

3.0 SULFIDE OXIDATION RESULTS FROM OxCon TESTWORK

The calculated change in oxygen concentration within an OxCon apparatus containing a pyrite/marcasite sample from a brown coal mine is shown in Figure 1 below. The sample had a total sulfur content of 29 wt.% S and the sample was finely milled (grain size minus 100 μm) prior to the commencement of OxCon testwork. It was assumed that all of the sulfur present in the sample was in the form of FeS₂, so the pyrite equivalent content was calculated to be 54 wt.%.

The oxygen concentration within the OxCon vessel decreased from an initial value of 20.95 vol. % O₂ (oxygen concentration value in the atmosphere at sea level) to 0 vol % after approximately 14 days.

The rate of oxygen consumption is used to determine the pyrite oxidation rate using the stoichiometric ratio in Equation 1, and the mass of available pyrite in the sample.

The experimental data indicate that the oxidation of pyrite as a function of oxygen concentration is consistent with a first order reaction with a rate constant of 0.351 day⁻¹. Figure 1 shows that oxygen consumption rate, and hence pyrite oxidation rate, remained relatively constant until oxygen concentrations fell below approximately 15 vol.%. Pyrite oxidation rates were still significant between 5 and 2.5 vol.% oxygen, but substantially lower than at atmospheric oxygen concentration levels.

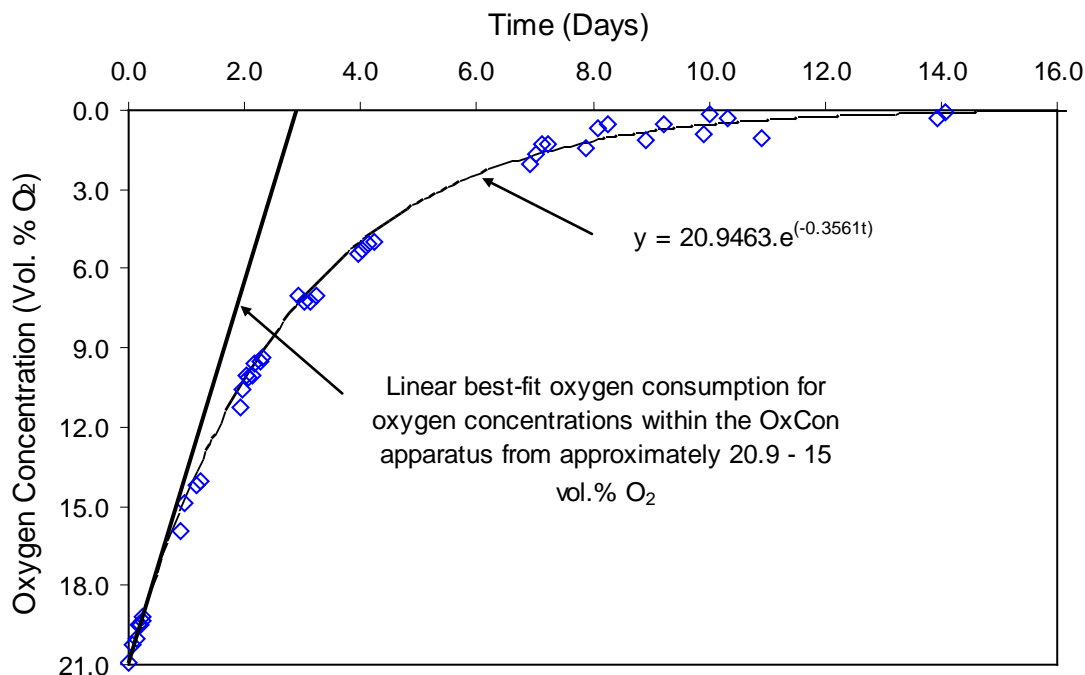


Fig. 1: Oxygen concentration (volume %) decreasing over time (days) as a result of the oxidation of a pyrite/marcasite sample from a coal mine (grain size <100 μm).

The slope of the trend defined by the data plotted in Figure 1 can be used to obtain oxygen consumption rates / pyrite oxidation rates at any point in time.

In general, the trend described by the data during the initial stages of the testwork approximate a straight line, whose slope represents the oxygen consumption rate for the given time interval. The oxygen consumption rate obtained from the linear fit of the data can be used to derive the “initial pyrite oxidation rate”.

Based on this approach, the initial pyrite oxidation rate for the milled pyrite/marcasite sample shown in Figure 1 was calculated to be 2.3 wt.% (FeS₂)/ year. The same material yielded an oxidation rate of 2.13 wt.% (FeS₂)/ year using conventional column leach experiments (McIlwaine, 1997). This study reports sulfide oxidation rate data in units of weight percent of pyrite (exposed to atmospheric oxygen) that is converted to sulfuric acid per year (wt.% FeS₂ converted / year) as shown in Table 1 below. Alternatively, sulfide oxidation rate data can be reported in units of kilograms of oxygen consumed per kilogram of material per second (kg O₂ / kg (material) / sec) or units of kilograms of sulfur oxidised per tonne of material per year (kg S / tonne (material) / year). The alternative units do not normalise the oxidation rate to the unit sulfide content of the material. By relating the oxidation rate to the sulfide content of the sample it is easier to apply to the pyrite oxidation rate, and therefore the pollution generation rate, to a waste rock pile with a known sulfide content.

Table 1: Sulfide oxidation rates as reported by Earth Systems, ANSTO and EGi (Environmental Geochemistry International).

Reported By	Equivalent Pyrite Content (wt. %)	Pyrite Oxidation Rate	Units
Earth Systems	1.00	1.00	wt. % (FeS ₂) / year
ANSTO	N/A	3.17 x 10 ⁻¹²	kg (O ₂) / kg (material) / sec
EGi	N/A	0.05	kg (S) / t (material) / year

A comparison of the decrease in oxygen concentrations over time for two samples of pyrite/marcasite from the same brown coal mine (both approximately 54 wt.% pyrite) is shown in Figure 2. The two samples differed in grain size only. One sample was milled to a grain size of less than 100 µm while the other sample comprised of minus 30 mm aggregate. After 7 days the milled sample had consumed almost all of the oxygen in the apparatus. After approximately 60 days the oxygen concentration in the apparatus containing the minus 30 mm aggregate sample was approximately 16 vol.%.

The decrease in oxygen concentration over time for a sample of Proterozoic Mount McRae (pyritic) Shale from the Pilbara region of Western Australia is also shown in Figure 2. The pyrite content of the shale was 12.6 wt. %. Despite the large difference in geologic histories and pyrite contents of the Mount McRae Shale (12.6 wt.% pyrite) and the pyrite/marcasites sample from the Brown Coal mine (75 wt.% pyrite), the normalised pyrite oxidation rate of both minus 30 mm aggregate samples was similar.

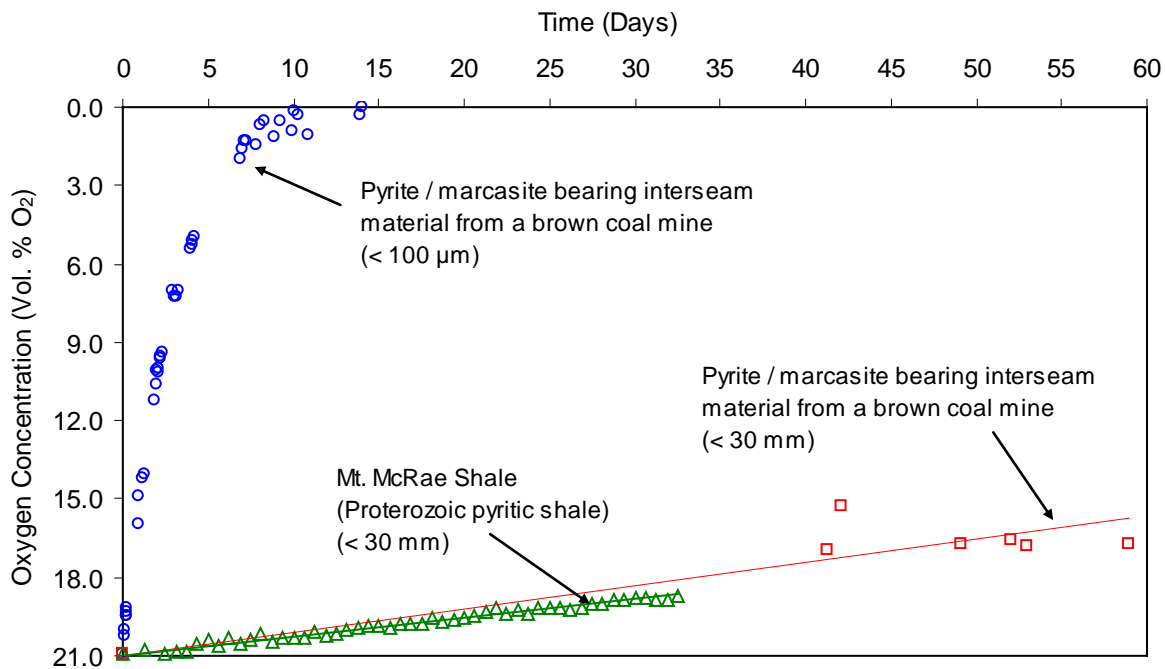


Fig. 2: Oxygen concentration (volume %) decreasing over time (days) as a result of sulfide oxidation in pyrite/marcasite samples from a brown coal mine (grain sizes <100 μm and -30 mm aggregate) and Mount McRae Shale (-30 mm aggregate). The oxidation rate is based on initial reductions in oxygen concentration (ie. down to approximately 19 vol.% O₂).

The sulfide oxidation rates determined using oxygen consumption techniques for a broad range of geologic materials are displayed in Figure 3. Some of this data has been generated from OxCon testwork, and other oxidation rate data obtained from published literature (Anderson et al. 1999; Borma et al. 2003; Di Nanno et al. 2007; Eidsa et al. 1997; Hollings et al. 2001; Morse 1991; Rigby et al. 2006)., is provided for comparison. Samples include sulfidic metal and coal mine wastes and acid sulfate soils. Oxidation rates vary over approximately 8 orders of magnitude, with sandy acid sulfate soil materials providing some of the most rapid oxidation rates (eg. 1-3 wt.% FeS₂/day). The oxidation rates of some of these materials have been tested as a function of sample moisture content. For both pyritic mine wastes and sandy acid sulfate soil materials, an increase in gravimetric moisture content is directly related to a decrease in sulfide oxidation rate.

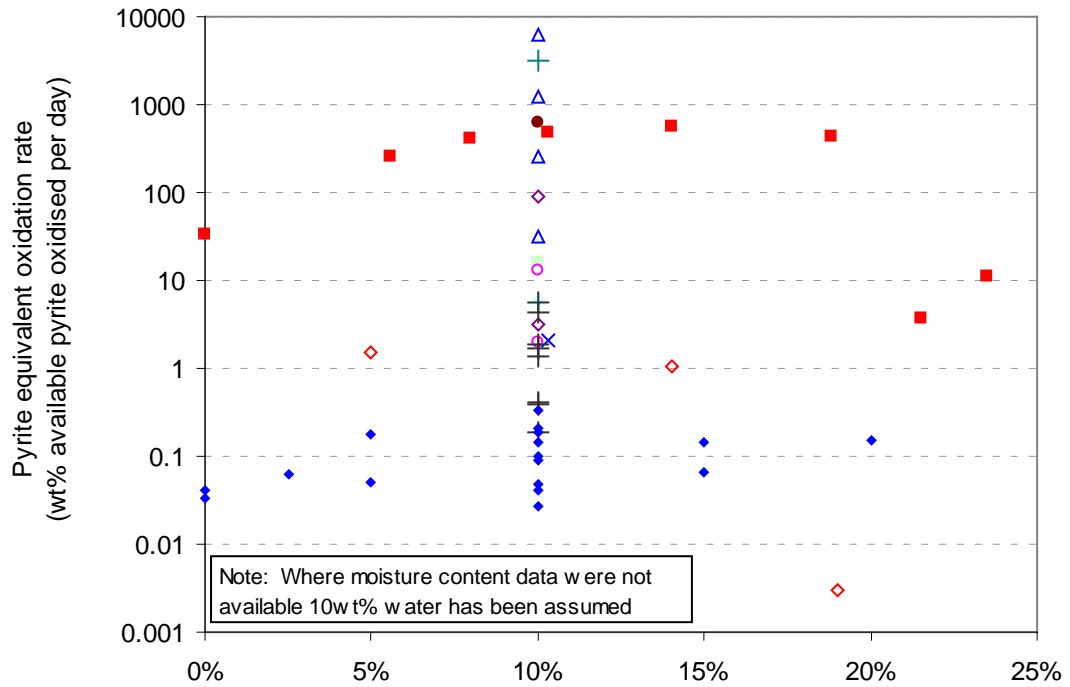


Fig 3. ■ Sandy acid sulfate soil. Earth Systems internal data
 ◇ Lagoon sediments. Borma et al. (2003)
 ● Acid sulfate soil. Rigby et al. (2006)
 + Sediments with microbial and nutrient inoculation. Di Nanno et al. (2007)
 △ Marine sediments. Morse (1991)
 ◆ Sulfidic interseam material from a brown coal mine. Earth Systems internal data
 ■ Gold mine tailings. Earth Systems internal data
 × Sulfidic waste rock (Mine 1). Earth Systems internal data
 ◇ Sulfidic waste rock and tailings mixture (Mine 2). Earth Systems internal data
 ○ Nickel mine waste rock (pyrrhotite). Anderson et al. (1999)
 + Base metal mine ore. Eidsa et al. (1997)
 ◆ Uranium mine waste rock. Hollings et al. (2000)

Fig. 3: Pyrite oxidation rates as a function of moisture content for acid sulfate soils and sulfidic mine wastes from various mine sites world-wide. Where gravimetric moisture content data was unavailable, 10 wt.% water was assumed.

4.0 BENEFITS OF OxCon PROCEDURE

The OxCon procedure offers significant benefits relative to other geochemical testwork methods. These include:

- The OxCon procedure is more accurate, reproducible, low cost and very rapid relative to all other kinetic test methods that quantify sulfide oxidation rates.
- The OxCon procedure avoids all complications associated with the precipitation or dissolution of secondary sulfate-bearing mineral phases that are unavoidable with both column leach and humidity cell testwork.
- Oxygen consumption testwork is the only kinetic testwork procedure that permits accurate quantification of the effect of moisture on the inhibition of sulfide oxidation.
- Oxygen consumption is the only kinetic testwork procedure that permits the determination of sulfide oxidation rates as a function of the different oxygen concentrations likely to be encountered in a broad range of geologic settings (eg. tailings and waste rock accumulations).
- OxCon testwork also enables easy and independent assessment of sulfide oxidation rates as a function of sulfide type, sulfide concentration, grain size, temperature, metamorphic terrain / geologic history.
- The OxCon procedure is the only kinetic testwork method that permits simultaneous but independent assessment of carbon oxidation rates, or quantifies carbonate neutralization reactions during the test.
- Like column leach or humidity cell testwork, OxCon testwork also permits an assessment of the leachate water quality, and thereby independently checks sulfate release rates. In providing a comparison between oxygen consumption rates and sulfate release rates, it is also possible to quantify the role of secondary sulfate salts in acidity generation.
- OxCon apparatus design is simple, cost effective and flexible, and can be scaled or customised for different applications (eg. in-situ highwall sulfide oxidation rates).

Based on these benefits, it is concluded that oxygen consumption methods should become a standard geochemical kinetic test to complement existing geochemical characterisation procedures.

5.0 CONCLUSIONS

Key conclusions from OxCon data available to date include:

- For the materials tested to date, pyrite oxidation rates does not decrease significantly with oxygen concentration until the oxygen concentration falls below approximately 15 vol. %.
- Sulfide oxidation continues at significant rates even at very low oxygen concentrations.
- The pyrite oxidation rate increases substantially with a decrease in the grain size of the sulfidic material.

- The pyrite oxidation rate decreases with an increase in moisture content, presumably largely due to the impact of moisture on retarding oxygen diffusion.
- Acid sulfate soils have far higher oxidation rates than the metamorphosed pyritic material common to most metal and coal mines, but also display a much finer grain size.

6.0 IMPLICATIONS FOR MANAGING SULFIDIC MATERIALS

The implications of OxCon testwork for the management of sulfidic materials include:

- The OxCon apparatus can be used to construct and quantify the effectiveness of various waste storage facility designs and remediation scenarios.
- The OxCon apparatus can be used to quantify the effectiveness of various water cover scenarios for a tailings storage facility or waste rock dam.
- Accurate quantification of the likely acidity generation rates from various site domains (eg. waste rock piles, tailings storage facilities or highwalls) assists with planning for operations and closure.
- The role of the moisture content of sulfidic materials to retard oxidation can be more accurately quantified, and hence the moisture retention benefits of paste tailings, paste rock and other co-disposal options can be quantified. This quantification will be comparable to measuring the influence of moisture on decreasing “air entry values” into sulfidic materials.
- It is important to note that decreases in oxygen concentration have little effect on pyrite oxidation until concentrations fall below 15 vol.%. This places significant challenges on management or remedial methods that rely on oxygen consumption.
- The available data suggests that oxygen concentrations need to fall well below 5 vol.% in underground mines with GaRDS installations (Taylor and Waring, 2001) before substantial reductions in acidity generation can be expected.

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