

Acid Based Accounting (ABA) for Acid Mine Drainage Prediction

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Acid Based Accounting for Acid Mine Drainage Prediction

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DECLARATION

I hereby declare that I have conducted, completed the research work and written the dissertation entitled 'Thesis Title'. I also declare that it has not been previously submitted for the award of any degree and diploma or other similar title of this for any other examining body or University.

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Abstrak

Dalam beberapa tahun ini, saluran lombong asid menjadi semakin serius di Malaysia. Contohnya, di Pahang, terdapat 3 tapak lombong terbiar iaitu badan air sudah berasid. Kajian ini bertujuan untuk mengkaji potensi saluran lombong asid dan pencirian tailing lombong emas dari lombong emas Kelantan, Tanah Merah. Sampel larut lesap Vat (VL) dan tailing Timbunan larut lesap (HL) dianalisis untuk potensi pengeluaran Saliran Lombong Asid (AMD). Sampel telah diperiksa melalui pemerhatian visual, dengan mata, dianalisis oleh Pembelaan sinar-X (XRD), Pendarfluor sinar-X (XRF) dan penganalisis sulfur Karbon Hidrogen Nitrogen (CHNS). Bagi ujian statik, ujian Acid Based Accounting (ABA) dan Net Acid Generation (NAG) dengan Paste Ph telah dilakukan. Daripada ABA, hasil Neutralizing Potential (NP) diperoleh dan ditolak dengan Acid Potential (AP) untuk mendapatkan nilai Net Neutralizing Potential (NNP). Ujian kinetik ialah ujian reaktor kelompok. Conklusi utama projek fyp ini adalah sample VL degna sampel HL bukan pengeluaran saluran lombong asid. Had yang ditemui oleh projek adalah, untuk penentuan NAG, suhu yang diperlukan sukar untuk dikekalkan pada keadaan mantap untuk jangka masa yang lama, dan dalam penentuan potensi Meneutralkan, menggunakan penarafan fizz semata-mata untuk menganggarkan jumlah HCl yang diperlukan sebenarnya tidak berpuas hati. Dalam kajian masa depan mengenai tailing emas, kajian mungkin boleh memfokuskan kepada melakukan perbandingan hasil sampel tailing dengan ujian statik yang berbeza, untuk melihat bagaimana kaedah yang berbeza memberikan nilai yang berbeza, dan mencari kawapan untuk menjawab kenapa HL berwarna merah kekuningan.

Abstract

In these recent years, acid mine drainage becoming serious in Malaysia. For example, in Pahang, there are 3 abandoned mine site that is water bodies already acidic. This study is aimed to investigate the acid mine drainage potential and characterization of the gold mine tailing from Kelantan, Tanah Merah gold mine. The sample Vat leaching (VL) and Heap leaching (HL) tailing are analyzed for potential Acid Mine Drainage (AMD) production. The samples were inspected by visual observation, analyzed by X-ray Diffraction (XRD), X-ray Fluorescence (XRF) and Carbon Hydrogen Nitrogen sulfur analyzer (CHNS). For the static test, Acid Based Accounting (ABA) test and Net Acid Generation (NAG) with Paste Ph was done. From ABA, the result of Neutralizing Potential (NP) is obtained and subtracted with Acid Potential (AP) to get the value of Net Neutralizing Potential (NNP). The kinetic test is a batch reactor test. The finding of the project is VL, and HL samples are non-acid mine drainage production. The limitation of the project would be, for the determination of NAG, the temperature required is difficult to maintain at steady state for a long time, and in the determination of Neutralizing potential, using solely fizz rating to estimate required amount of HCl is not really satisfied. In future study regarding the gold tailing, study might can focus on doing on comparing result of the tailing samples with the different static test, to see how different method gives different values, and finding on reason that the solution of HL was red yellowish.

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List of Symbol

%	Percentage
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List of abbreviations

AMD Acid Mine Drainage

VL Vat Leaching

HL Heap Leaching

XRF X-Ray Fluorescence

XRD X-Ray Diffractions

ABA Acid Base Accounting

NAG Net Acid Generation

AP Acidity Potential

MPA Maximum Potential Acidity

NP Neutralization Potential

ANC Acid Neutralizing Capacity

NNP Net Neutralizing Potential

List of equation

$$NAG = (49 \times vB \times bM) / sW \dots\dots\dots Eq4.1$$

$$NP [kg \text{ CaCo}_3/T] = [50ax - 50by] / c \dots\dots\dots Eq4.2$$

$$M_1V_1 = M_2V_2 \dots\dots\dots Eq4.3$$

Chapter 1

Introduction

1.1 Background of the study

Mining is first and foremost a source of an important economy that every one country finds essential for maintaining and improving their standards of living. Mined materials are needed to construct roads and hospitals, build automobiles and houses, make computers and satellites, generate electricity, and supply various other goods and services to sustain human civilization.

In addition, mining is economically essential to developing regions and countries. It provides employment, dividends, and taxes that obtain hospitals, schools, and public facilities. The mining industry produces a trained workforce and professional laborers, small and medium businesses, that may service communities and will initiate related domestic demand Mining also yields exchange and accounts for a major portion of the gross domestic product of a nation. Mining provides the drive of several associated industry, like the manufacturing of mining equipment, provision of engineering and environmental services, and therefore the development of world-class universities within the fields of geology, mining engineering, and metallurgy. The economic opportunities and wealth generated by mining for several producing countries are essential (US National Research Council (NRC) 2002).

That mining can be a sector that will conduct serious irreversible damage to the environment, it's suggested that some general principles may be done such that:

Ensure the company's environmental policy and operations transcend meeting current regulatory standards. The operations must exemplify best contemporary practices for the minimization and, where feasible, elimination of adverse environmental effects. the corporate does so by incorporating environmental matters as a basic part of short- and long-range planning for all projects and operations.

The company should accommodate all applicable environmental laws, regulations, and prescribed standards and criteria, and make sure that its contractors do. And participating in the development of environmental legislation promoting and, where feasible, implementing new or simpler practices for environmental protection, compliance, and emergency response to any accident (National Academies of Sciences, Engineering, and Medicine. 1997).

1.2 Problem statement

Acid drainage could be a global crisis that's little or not known by most of the public. The United Nations (UN) has even labeled it the second biggest problem facing the globe after warming (Global Citizen. 2022). Acid mine drainage is every one of the massive problems with most hard rock mines, especially when the mines where the metal ore is bound up with sulfur. The metals dissolved by the acid drainage with very low Ph poison downstream waters which can create a biological dead zone downstream, in many cases to the purpose where nothing aside from microbes can survive. acid mine drainage generation is incredibly difficult to manage or perhaps p it and might continue producing drainage for tens of thousands of years until the available sulfide minerals are depleted. it's found that Roman-era mines are still producing acid mine drainage even to the present day. Mini is it the irreversibility process of turning relatively unreacted ore into

tremendous volumes of hazardous waste that speed up the relatively slow reaction thanks to excavation, the very long hazard-life of the fabric poses to the environment, and also the extreme difficulty of containment which makes mine drainage such a heavy and persistence issue.

For the problem of acid mine drainage in Malaysia, based on a study by Kishan Gunesegeeran et al (2021), development activities involving land, mining and agriculture are carried out on upstream of the Old Repas dam in Bentong, Pahang have resulted in the deterioration of water quality. The precipitation of heavy metals has contaminated the water bodies, wastewater, and surface runoffs. All the water will reach the Betong dam, and the pollution will affect the aquatic life there. The authors sampled sampling 4 points of water around the dam and found out all the points around are all acidic water. Not only this, the concentrations of heavy metals such as Arsenic, zinc, and tin are very high. The authors state, based on the water classification of National water quality standard (NWQS), It was classified as class V which is heavy pollution.

Previous work by athirah et al (2018) showing that on four abandoned mine sites in Pahang, which is Kg Aur, Tasik Chini, Sungai Lembing, and Quarry Kg Awah, the pH values of water in Kg Aur, Chini and Sungai Lembing are very low. This create concern in which the low pH of water may lead to further dissolution for heavy mineral. The works conclude that Sungai Lembing are the highest potential to generate acid drainage.

1.3 Objective

The study of this project is to investigate the tailing sample from a gold mine in Kelantan. The result from this project will shed some light on the best method to obtain Acid Mine

Drainage result in the future for any sample from this gold mine. The objective of this project is as follows:

- 1) To characterize the geochemistry characteristic of the samples of Heap Leaching tailing and Vat Leaching tailing.
- 2) To determine Acid Based Accounting (ABA) for acid mine drainage.

1.4 Scope of works

In the doing of this project, the works done are geochemical characteristics by using Phase identification of XRD, Elemental analysis of XRF, and Carbon Hydrogen sulphur nitrogen Analyzer (CHNS) to analyze the sample.

For the determination of acid mine drainage, the static test and kinetic test are used.

Static test consists of Acid Based Accounting (ABA). Net Acid Generation (NAG), Acid Potential test (AP), Neutralizing test (NP) and Paste pH. While Kinetic test used is the Batch reactor test.

The limitation is for the determination of NAG, the temperature required are difficult to maintained at steady state for long time, and in determination of Neutralizing potential, using solely fizz rating to estimate required amount of HCl is not really satisfied.

Chapter 2

Literature Review

2.1 Introduction

Acid mine Drainage is acidic water coming from mining activity and other acts. While the natural weathering process produces AMD also, the size and problem of AMD production are negligible compared to act.

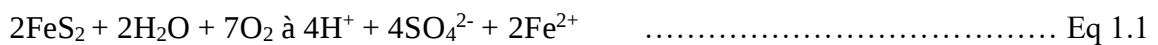
The geochemical test work will be accustomed help with the Acid Mine Drainage components of the Environmental and Social Impact Study as needed by the EIA report requirements, and also give relevant data for the event of the latest mining sites when considering the pre-feasibility and feasibility stages of developing mining method. This greatly helps with mine planning, mine operations, and also mine closing strategies (Davis et al., 2019).

during this chapter, the mechanism of manufacturing AMD by sulfide minerals thanks to mining activity is discussed. By using one in every of the foremost common sulfide minerals pyrite, FeS_2 , how the oxidation of pyrite mineral produces AMD as discussed well. the categories and mechanisms of geochemical test works that are accustomed to determining occurrence by statics and Kinetic tests are going to be discussed very well. Also, the tactic of conducting static tests and kinetic tests yet as their advantages and drawbacks are presented similarly.

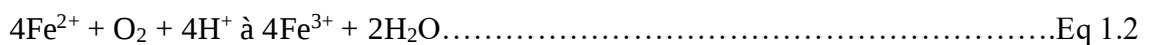
2.2 Acid Mine Drainage (AMD)

The acid is generated at mine sites when metal sulfide minerals are oxidized. Metal sulfide minerals are present within the host rock and are related to most styles of metal mining

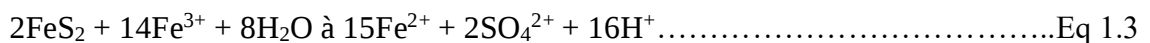
activity. Before mining, the oxidation of those minerals and also the formation of acid are a function of natural weathering processes. The oxidation of undisturbed ore bodies followed by the discharge of acid and mobilization of metals is slow. Discharge from such deposits poses little threat to receiving aquatic ecosystems. Extraction and beneficiation operations related to mining activity increase the speed of those same chemical reactions by exposing large volumes of sulfide rock material with increased area to air and water. The oxidation of sulfide minerals consists of several reactions. Each sulfide mineral includes a different oxidation rate. as example, marcasite and framboidal pyrite will oxidize quickly while crystalline pyrite will oxidize slowly. The oxidation of pyrite is the typical chemical reaction that can produce AMD.



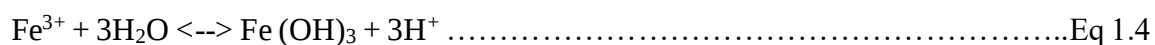
In this step, S²⁻ is oxidized to form hydrogen ions and sulfate, the dissociation products of sulfuric acid in the solution. Soluble Fe²⁺ is also free to react further. Oxidation of the ferrous ion to ferric ion occurs more slowly at lower pH values:



At pH levels between 3.5 and 4.5, iron oxidation is catalyzed by a variety of Metallogenies, a filamentous bacterium. Below a pH of 3.5, the same reaction is catalyzed by the iron bacterium *Thiobacillus ferrooxidans*.



This reaction generates more acid. The dissolution of pyrite by ferric iron (Fe³⁺), in conjunction with the oxidation of the ferrous ion, constitutes a cycle of dissolution of pyrite. Ferric iron precipitates as hydrated iron oxide as indicated in the following reaction:



Fe(OH)₃ precipitates and is identifiable as the deposit of amorphous, yellow, orange, or red deposits on stream bottoms(Epa & of Wetlands, 1994).

2.2.1 Acid mine drainage problem in Malaysia

On a previous study of Marcus Jopony & Felix Tongkul (2009), on Mamut copper mine in Sabah, on a tailing dam called Lohan Tailing Dam (LTD), it is a tailing dam located in a valley about 1000 m below the mine. It is found that the water at Mamut Copper Mine have low pH, high acidity, high sulphate and elevated concentrations of dissolved heavy metals which is in particular Fe, Al, Mn, Cu and Zn. And the water is confirmed Acid Mine Drainage with Ph as low as 2.00.

A previous study of AMD on Sungai Lembing, Pahang by Ak Ahmad et. al. (2014), founds that the water pH in Sungai Lembing varies from 4.37 – 6.11 with 5 sampling area. The pH are different with different water sampling area, but overall the water are acidic and below 5 in 4 of the area and only one area with pH of 6.11. The reviews also point out that the heavy metal concentration from the ex-mine are much higher than the earth background concentration of heavy metal. The review warn that the elevated heavy metal already heavily polluted the river, and actions have to be taken to tackle the problem.

2.3 Geochemical characteristic

In the previous study of Anita Parbhajjar-Fox and Bernd G. Lottermoser (2015), the determination of what kind of characterization tools to be used are based on selection of the objective of the research. For instance, depending on the sample mineralogical composition is required for calculating the calcite and sulphide or whether the elemental

composition of a specific sample is important to be analyzed to understand its relative susceptibility to oxidation. In the study of the sample that are involving sulphide minerals, electron microprobe analysis (EPMA), laser ablation inductively coupled plasma mass spectrometry (LA-ICPMS), micro-PIXE and micro-XRF is restricted to be used because compositional abnormalities affect ARD test work interpretation.

2.3.1 Phase identification by X-ray Diffraction

X-ray diffraction is based on constructive interference of monochromatic X-rays and a crystalline sample. These X-rays are generated by a cathode ray tube, filtered to produce monochromatic radiation, collimated to concentrate, and directed toward the sample. The interaction of the incident rays with the sample produces constructive interference (and a diffracted ray) when conditions satisfy Bragg's Law ($n\lambda=2d \sin \theta$). This law relates the wavelength of electromagnetic radiation to the diffraction angle and the lattice spacing in a crystalline sample. These diffracted X-rays are then detected, processed, and counted. By scanning the sample through a range of 2θ angles, all possible diffraction directions of the lattice should be attained due to the random orientation of the powdered material. Conversion of the diffraction peaks to d-spacings allows identification of the mineral because each mineral has a set of unique d-spacings. Typically, this is achieved by comparison of d-spacings with standard reference patterns (Worku Wubet 2019).

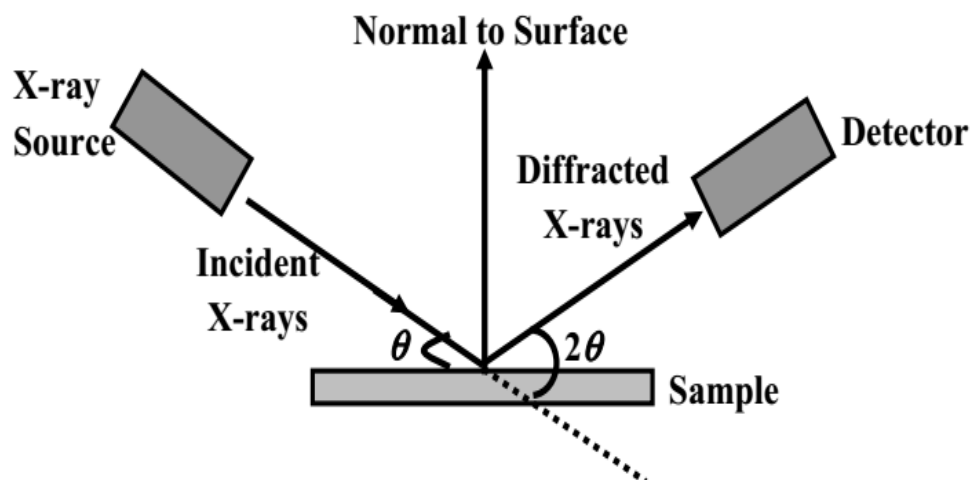


Figure 2.1: X-ray diffraction principle after (Worku Wubet 2019)

2.3.2 Elemental compositional Analysis

The elemental compositional analysis are done by X-ray Fluorescent. The principle for XRF is that, for particular energy (wavelength) of fluorescent light emitted by an element, the number of photons per unit time (generally referred to as peak intensity or count rate) is related to the amount of that analyte in the sample. The counting rates for all detectable elements within a sample are usually calculated by counting, for a set amount of time, the number of photons that are detected for the various analytes' characteristic X-ray energy lines. It is important to note that these fluorescent lines are observed as peaks with a semi-Gaussian distribution because of the imperfect resolution of modern detector technology. Therefore, by determining the energy of the X-ray peaks in a sample's spectrum, and by calculating the count rate of the various elemental peaks, it can qualitatively establish the elemental composition of the samples and quantitatively measure the concentration of these elements.

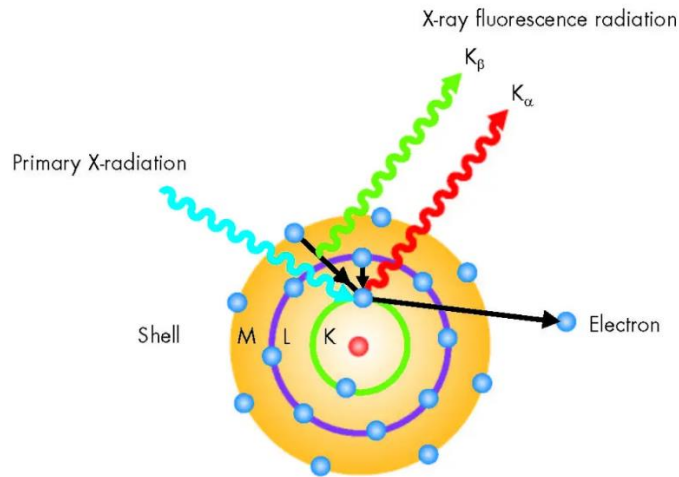


Figure 2.2: X-Ray Fluorescence Principle after (Fischer n.d.)

The specimen is excited with the primary X-radiation. In the process electrons from the inner electron shells are knocked. Electrons from outer electron shells fill the resultant voids emitting a fluorescence radiation that is characteristic in its energy distribution for a particular material. This fluorescence radiation is evaluated by the detector.

The generation of the X-ray fluorescence radiation is shown simplified in the figure above. One electron from the K shell is knocked. The resultant void is filled by either an electron from the L shell or an electron from the M shell. In the process the K_{α} and K_{β} radiation is generated, which is characteristic for the material.

2.3.3 Carbon, hydrogen, Nitrogen, sulphur Analyzer (CHNS)

Basic principles of CHNS is that, in the combustion process (furnace at 1000°C), carbon is converted to carbon dioxide; hydrogen to water; nitrogen to nitrogen gas/ oxides of nitrogen and sulphur to sulphur dioxide. If other elements such as chlorine are present, they will also be converted to combustion products, such as hydrogen chloride. A variety

of absorbents are used to remove these additional combustion products as well as some of the principal elements, sulphur for example, if no determination of these additional elements is required. The combustion products are swept out of the combustion chamber by inert carrier gas such as helium and passed over heated (about 600o C) high purity copper. This copper can be situated at the base of the combustion chamber or in a separate furnace. The function of this copper is to remove any oxygen not consumed in the initial combustion and to convert any oxides of nitrogen-to-nitrogen gas. The gases are then passed through the absorbent traps to leave only carbon dioxide, water, nitrogen and sulphur dioxide. Detection of the gases can be carried out in a variety of ways including

- (i) a GC separation followed by quantification using thermal conductivity detection
- (ii)** (ii) a partial separation by GC ('frontal chromatography') followed by thermal conductivity detection (CHN but not S)
- (iii)** (iii) a series of separate infra-red and thermal conductivity cells for detection of individual compounds. Quantification of the elements requires calibration for each element by using high purity 'micro-analytical standard' compounds such as acetanilide and benzoic acid.

CHNS elemental analysers provide a means for the rapid determination of carbon, hydrogen, nitrogen and sulphur in organic matrices and other types of materials. They are capable of handling a wide variety of sample types, including solids, liquids, volatile and viscous samples, in the fields of pharmaceuticals, polymers, chemicals, environment, food and energy (Michael Thompson 2008).

2.4 Geochemical Test work

Static tests are intended to predict whether a sample and also the rock or soil that it represents, are going to be acid-producing after exposure to weathering. Nevertheless, static tests are widely used because they need the benefits of being rapid and straightforward to perform, and commensurate with those advantages could be a relatively low cost per determination. Hence, static tests are commonly performed on large numbers of samples for a personal project, and for potentially exploitable mineral and coal deposits the results have commonly accustomed to a guide on which rocks may merit further kinetic tests. At active mines, static tests could also be an accustomed monitor or the potential of assorted wastes, like overburden and barren or sulfide-bearing low-grade rocks that host the ores, to come up with acidic drainage.

The characteristic of a static test from a kinetic test is that it's a one-time determination, whereas kinetic tests involve repeated cycles during which dosages of humidity or aqueous solutions are applied over a period. Thus, kinetic tests can provide information on weathering rates and therefore the abundances of ions within the leachates, data that aren't obtainable from a static test.

Kinetic tests are attempted to mimic natural oxidation reactions of the sector setting. The tests typically use a bigger sample volume and need a far longer time for completion than static tests. These tests provide information on the speed of sulfide mineral oxidation and so acid production, furthermore as a sign of drainage water quality. Of the various kinetic tests used, nobody evaluation test is preferred. The preference for tests changes with time as experience and understanding increase. (Epa & of Wetlands, 1994a)

Kinetic tests will be used to assess the impact of various variables on the potential to come up with acid. as an example, samples are also inoculated with bacteria, and therefore the temperature of the sample environment might also be controlled during the test. Most tests require the sample particle size to be but a specified sieve size with larger sample volumes and equipment may examine acid potential from coarse particles. Acid drainage control mechanisms, like increasing alkalinity by adding lime, can also be examined using kinetic tests.

2.4.1 Static Test (Acid Base Accounting)

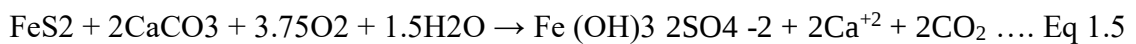
Acid-based accounting could be a method using statics tests. it's done by evaluating the overall acid generating potential and therefore the total acid neutralization potential. By having acid formation potential and neutralization potential, then the acid mine drainage will be calculated because of the differences between these two values. It also can be determined by doing the ratios of values. The acid-based accounting method doesn't measure and offers any values about the speed of acid production.

As mentioned by Skousen et al (2002) ABA is the most used method for predicting post-mining water quality, kinetic, or leaching. These leaching tests are especially useful where the acid-producing and acid-neutralizing are nearly balanced, where one doesn't overwhelm the opposite. Leaching tests often provide additional information that supplements the ABA data and per se provides a crucial assessment that's not available from static tests like ABA.

The MPA is the maximum amount of sulphuric acid that may be produced from the oxidation of sulfur minerals in rocks or overburdened material. acid production is related

to pyritic sulfur, the ABA procedure typically measures total sulfur because it's easier to live than pyritic sulfur.

The simplest and most often used method of total S determination is high-temperature furnace combustion. This method gives a percent of sulfur present within the rock and is multiplied by a relentless to work out the MPA in Mg/1000 Mg, by a relentless to work out the MPA in Mg/1000 Mg, which is comparable to the NP determination.



where 1 mole of FeS₂ (64 g of sulfur) is neutralized by 2 moles of CaCO₃ (200 g of CaCO₃). Therefore, the constant is 31.25, which means that it takes 31.25 Mg of CaCO₃ to neutralize 1000 Mg of rock containing 1% pyritic sulfur.

2.4.2 Advantages and disadvantages of Static Test

In a review article by Acharya & Kharel, (2020), the static test that can be used as acid mine drainage predictions along with their advantages and disadvantages are shown in the following table of 2.1.

The different static methods show in the table are all using the sample concept of multiplying the total sulphur percentage with 31.25, but the method on conducting the different static experiment have large variations. The normal acid based accounting and the modified acid based accounting are basically different test, as ABA only boils and cool after adding acid, while the Modified ABA needs to maintain a certain pH range and waiting for 24H before titration.

The table shows the advantages and disadvantages of a few different methods of static tests. All the method shown in the table are all using total Sulphur to determine the acid

except Net acid generation by using Hydrogen Peroxide to oxidize the sample, they are all in common easy to interpret and does not need any special equipment. While for disadvantages, the Acid Based Accounting and the Modified Acid Based Accounting are hard to relate to the kinetic test data, and for Net and Generation, the data are hard to be experiment reproducible, and it has big uncertainties as the oxidation rate of the sample will depend largely on sulfide mineral oxidation rate. There is also major disadvantages for the Acid based Accounting, BC research initial and Modified Acid based accounting, when the result of AP and NP are too close, it will be very hard to interpret for the potential of acid mine drainage.

The authors also state that static and kinetic tests are used in acid rock drainage prediction and that the calculation factor of 31.25 overestimates the neutralization potential of carbonate by roughly 100%. Additionally, ABA underestimated the acid potential of Fe^{3+} hydroxides and sulfates and failed to discern different carbonate minerals.

The modified ABA method excludes non-sulfide sources in sulfur assuming sulfate as a non-acid producing source. This assumption leads to the underestimation of APP when jarosite is present in large quantities in waste materials.

Table 2.1 Summary of Static Test Methods, Advantages, and Disadvantages after (Epa & of Wetlands, 1994)

Acid Based Accounting after (Sobek et al, 1978)	MODIFIED Acid Based Accounting After (Coastech, 1989)	BC RESEARCH INTIAL after (Duncan and Bruynesteyn, 1979)	Alkaline Production Potential: Sulfur (Caruccio et al, 1981)	Net Acid Production After (Coastech 1989)
ACID PRODUCTION DETERMINATION				
Acid Producing Potential = 31.25 * Total S	Acid Producing Potential = 31.25 * Total S	Total Acid Production = 31.25 * Total S	Total S used as an indicator	300 mL H ₂ O added to 5 g rock to directly oxidize sulfides present

NEUTRALIZATION POTENTIAL DETERMINATION				
-60 mesh (0.24 mm) sample add HCl as indicated by fizz test, boil one minute then cool titration end point pH 7.0	-60 mesh (0.24 mm) sample add HCl as indicated by fizz test agitate for 23 hours at room temperature pH 1.4 - 2.0 required after six hours agitation titration end point pH 8.3	-300 mesh (0.038 mm) sample titrate sample to pH 3.4 with 1.0 N H ₂ SO ₄ titration endpoint not applicable	0.023 mm sample 20 mL 0.1 N HCl to 0.4g solid for 2 hours at room temperature titration end point pH 4.0	particle size not presented acid produced by iron sulfide oxidization dissolves buffering minerals titration end point pH 7.0
ADVANTAGES AND DISADVANTAGES				
a simple and short time no special equipment and easy interpretation many samples can be tested does not relate to kinetic	simple, short time, no special equipment, and easy interpretation does not relate to kinetic assumes	simple and fairly short time, no special equipment and easy interpretation many samples can be tested, assumes parallel acid/	simple, short time and no special equipment required	simple, short time, no special equipment, and easy interpretation limited reproducibility uncertain if the extent of sulfide

assumes parallel acid/ alkaline release if APP and NP are close, hard to interpret and different particle sizes not reflected	parallel acid/ alkaline release if AP and NP are close, hard to interpret and different particle size not reflected	alkaline release, different particle size not reflected, and if APP and NP are close, hard to interpret		oxidation simulates that in field
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Literary criticism by Karlsson et al. (2018), states that the limitation of ABA is that Some carbonate minerals containing iron, particularly siderite (FeCO_3), don't necessarily contribute to neutralization. the strategy doesn't consider the reactive non-carbonate minerals that will contribute to acid neutralization. The authors also criticized that the AP is calculated by multiplying the wt% of S by the factor 31.25 supporting the hypothesis that 2 mol of protons (released from pyrite oxidation) are neutralized by 1 mol of calcite, but in circumneutral pH which is Ph of around 5-7 the foremost common carbonate species is bicarbonate and therefore the calculation, factor should then be 62.5, as twofold more calcite is required to neutralize the identical quantity of protons.

The author also states that static ABA and NAG tests have known limitations associated with the mineralogy of the sample material APP could also be overestimated if there are other sulfides- or sulfur-containing minerals than rapidly acid-producing pyrite or pyrrhotite. The NP is also underestimated if the weathering of silicate minerals isn't considered in APP estimations, NP determined within the laboratory using strong acids will sometimes overestimate silicate mineral reactivity and also the NP.

The authors Skousen et al (2002) state that the overall net neutralizing potential (NNP) is decided for every stratigraphic layer by subtracting the MPA from the NP. a positive number indicates more potentially acid-neutralizing strata within the overburden and a negative number indicates more potentially acid-producing strata within the overburden. The NP to MPA ratio is solely computed by dividing the NP by the MPA. A ratio of 1 is is cherished NNP of 0. These values for every rock unit can then be wont to identify potentially acid-producing rock or overburden.

the employment of ABA data to predict post-mining water quality involves numerous assumptions:

- (i) all sulfur in a very sample will react to make acid,
- (ii) all material within the sample that consumes acid within the laboratory will generate alkalinity within the field
- (iii) the pyrite oxidation rate is a smaller amount than or adequate for the speed of carbonate mineral dissolution

The overburden determination is extremely important in estimating Volumes of every layer within the overburden were determined in 3 ways. the primary way (Ziem) was a right-triangle method modified. The cross-sectional area perpendicular to the highway was calculated from depth and pit width. The cross-sectional area of every layer was calculated by interpolation with layer depths and also the average slope. Layer volumes were calculated by multiplying layer cross-sectional area by total pit length.

A second method, Simmons and Skousen (S&S), may be modification of the Ziem method therein it separated each mining site into unique topographic shapes (concave vs. convex slopes, narrow vs. bowl-shaped valleys, steep vs. gentle slopes, etc.). Widths, lengths, depths, and slopes of unique shapes were measured, then the volumes for all the unique shapes on the positioning were summed together to get total overburden amounts. This method incorporated varying slopes and land surfaces into the quantity calculation.

The third method, the PADEP method Brady et al. (1994), used a planimeter to see the area of the upper- and lower-most strata within the mined area boundary. A spreadsheet then interpolated the upper and lower area of every layer, assuming a relentless slope, then

multiplied the common layer area by its thickness to get volume. The Ziem and PADEP methods were far less time-consuming in estimating volumes than the S&S method. Volumes for every method were then converted to mass by multiplying the degree of every stratigraphic unit by the unit weight of the rock type present.

Overburden volume estimates from three methods were converted to mass and compared with truck weights on five differently sized and shaped sites. The PADEP method was consistently closer to the overburden mass than the opposite two methods, giving a mean percentage error of only -4%. The Ziem method generally overestimated overburden mass. the typical percent error for the Ziem method was 118%, with a maximum of 320%. The S&S was better than the Ziem method, with a mean error of 23%, but consistently underestimated overburden masses and required considerably longer energy than the opposite two methods.

Despite large differences in overburden mass estimates, this had a surprisingly small effect on NP and MPA estimates among the methods. within the findings of this text, the authors found that comparing NNP with NP to MPA ratio for every site 56 mining sites, there was no difference within prediction of production acid or alkaline post-mining water. Sites with a negative NNP value were found to own a 1 NP to MPA ratio, and sites with a variety of 0.4 to 17.4 Mg/1000 Mg NNP were found to occur within the 1 to 2 NP to MPA ratio.

The previous study before the author of this text is that sites with overburden NP to MPA ratios 1 should produce acid mine drainage, while ratios 2 should produce net alkaline drainage. Those between 1 and a couple of could generate either acid, alkaline, or neutral drainage.

The author found that eight sites had NP to MPA ratios < 1 , and 6 of those sites produced net acid water, Of the eight sites that gave NP to MPA ratios between 1 and a pair of, only 1 produced net acid water, and only slightly. Forty of the 56 sites had NP to MPA ratios 2. Of 56 these sites, four produced net acid waters.

The author also states that NP alone wasn't a transparent indicator for acid post-mining water quality,

in general, the author's largest finding is an NP to MPA ratio of 1 will produce mostly acid drainage sites, between 1 and a pair of will produce mostly alkaline drainage sites, while an NP to MPA ratio of two will produce 40 alkaline drainage sites with some exceptions. The NP to MPA ratio is healthier because NNP (the difference between NP and MPA) is confounded by scale (the size of the mine and therefore the amount of overburden). during this article paper, the authors wonder if there exists any relationship existed between the scale of the mine (equating to total amounts of overburden moved) and net alkalinity of post-mining water small mines move less overburden and so have less chance of intercepting acid-neutralizing strata.

An article by Charles et al. (2015), reviewed the online acid generation test in ABA and states that it will be a sign of metal mobility during weathering and oxidation of the waste, and there are possible advantages to using NAG tests and derivations of the NAG test as a substitute for kinetic tests. But the authors also highlight the constraints of this test, which are when the test is completed on samples with elevated transition metal carbonate content can produce excessively basic NAG pH conditions which can be misleading and end in uncertainty in interpretation. it's hypothesized that the elevated pH conditions are

often attributed to carbonic acid gas (CO₂) disequilibrium during the heating stage of a NAG test.

2.4.3 Backgrounds ABA mine sites case study

In an article written by Skousen (2017), the author summarized nine principles for doing ABA analysis for acid mine drainage prediction. The authors used an analyzed table of the geological core log to illustrate the interpretation of acid-mine drainage.

Table 2.2: Principle of the ABA analysis method After (Skousen 2017)

Acid Base Account						Calcium carbonate equivalent				
						Mg/1000 Mg of material				
1	2	3	4	5	6	7	8	9	10	11
Sample layer	Bottom depth (m)	Rock type	Fizz (0–3)	Color	% Sulfur	Max from % sulfur	NP	Max needed	Excess	Paste pH
1	0.9	Soil	0	7/3	0.035	1.09	3.52		2.53	4.4
2	1.8	Sandstone	0	8/6	0.029	0.91	– 1.51	2.42		4.3
3	2.7	Sandstone	0	8/4	0.023	0.72	– 1.59	2.31		4.6
4	4.3	Shale	0	7/4	0.009	0.28	– 0.60	0.88		4.6
5	5.2	Shale	0	7/4	0.009	0.28	– 0.09	0.37		4.7
6	6.1	Shale	0	8/3	0.011	0.34	– 0.17	0.51		4.5
7	7.3	Mudstone	0	7/1	0.263	8.22	– 0.94	9.16		4.8
8	8.5	Mudstone	1	7/1	0.179	5.59	78.33		72.74	7.8
9	10.7	Mudstone	0	7/1	0.028	0.88	15.77		14.89	7.9
10	11.9	Mudstone	1	7/0	0.140	4.38	39.71		35.33	7.8
11	13.4	Mudstone	1	7/1	0.278	8.69	25.25		16.56	8.0
12	14.9	Shale	1	7/1	0.079	2.47	25.76		23.29	8.1
13	15.5	Mudstone	1	7/1	0.665	20.78	32.45		11.67	7.9
14	16.8	Shale	1	7/1	0.610	19.06	25.88		6.82	7.8
15	17.7	Shale	0	6/1	0.355	11.09	17.78		6.69	7.3
16	18.0	Shale	0	5/1	0.800	25.00	3.80	21.20		4.2
17	19.5	Coal	*	*	*	*	*	*	*	*
18	20.4	Mudstone	0	6/1	2.82	88.12	– 2.78	90.90		3.5

The author summarized the Principle of the ABA analysis method based on the above table:

- 1) Rock types and rock thickness. It is included in the analysis to categorize the type of rocks that will encounter at the mine site, and able to determine the amount of material in rock layers. Types of rock can provide information on how rock

behaves for base status when it undergoes weathering. The information is shown in the 2nd column and 3rd column.

2) The information of fizz, which is shown in the 4th column is a measure of the degree of bubbling when the cold diluted hydrochloride acid with a ratio of HCL: water of 1:3 is dropped onto the rock sample. The rating is from 0 to 3, with 0 indicating no bubbling and 3 indicating violent bubbling. Sample with a fizz rating of 1 having the level of NP of > 20Mg/ 1000Mg and a fizz rating of 3 results in NP of 200Mg/1000Mg.

3) The information of color can be used to determine the degree of oxidization by looking at the brownness and grayness of the rocks. The first number indicates the lightness or darkness of the rocks. The second number is used to indicate how much the rock had been oxidized or reduced status. If the number is 2 or less, then it is in reduced states and unweather. Rocks with more than number 2 then mean it's more weathered.

4) The values of paste Ph, in column 11th are determined by grounded rock mixed with water in a ratio of 1:1 by volume. Any rock sample that has a paste pH of 4 or less is characterized as acid-producing. Samples with pH values of > 7.5 have moderate to high levels of neutralization potential (NP).

5) The percentage of sulfur in the rock samples, with values under column 6th, will multiply by a conversion factor of 31.25, in which to get maximum acid potential, in which values under column 7th.