



Development of an electrical conductivity screening test for mine waste assessments



Mohammad Rezaee^a, Richard C. Warner^b, Rick Q. Honaker^{a,*}

^a 504 Rose Street, 230 MMRB, Department of Mining Engineering, University of Kentucky, Lexington, KY 40506, USA

^b 217 C.E. Barnhart Building, Department of Biosystems and Agricultural Department, University of Kentucky, Lexington, KY 40546, USA

HIGHLIGHTS

- Leaching characteristics of a waste stream from a coal processing plant were evaluated.
- The key factors impacting electrical conductivity of leachate were evaluated using statistical analyses.
- Leachant volume to particles surface area ratio and oxidant were the most significant parameters.
- A conductivity screening test was developed for assessing environmental impacts of waste streams.

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ABSTRACT

An environmental concern at mining operations is the potential leaching of trace elements from overburden and byproduct streams of processing plants. To provide a timely assessment of this concern, electrical conductivity of the leachate emanating from the plant waste streams can be measured as an indicator of the trace element content levels using the USGS Field Leach Test (FLT). However, the research reported in this publication revealed the need to modify the FLT procedure to improve the precision of the test results. The primary issue involved the importance of leachant volume-to-particle surface area ratio in the assessment of the leaching potential for a given source. To determine the key factors impacting leachability of a given material, a statistically-designed parametric study was performed. The experimental program evaluated the effects of particle surface area, the leachant volume-to-surface area ratio, and the amount of oxidant used to expedite the leaching rate during the test. The results revealed that the significant parameters are leachant volume-to-solid surface area ratio and the amount of oxidant. The findings were used to recommend a modification to the conductivity screening test.

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1. Introduction

The leaching of major and trace elements into streams and their potential environmental impacts are of environmental concerns especially for mine overburden, coal and mineral processing waste materials, naturally mineralized soil, industrial waste, construction sites, natural and amended soils, ash material from coal combustor units, dust, dried sludge and sediments, etc. (Daniels et al., 2013; Ghosh et al., 2014; Gluskoter et al., 2009; Hageman, 2007; Huggins et al., 2016; Plumlee et al., 2005; Van Gosen et al., 2000; Yager et al., 2004).

In processing plants, gangue minerals are separated from valuable minerals using low-cost separation technologies which improves the quality of raw material to a level that meets product quality requirements (Amini et al., 2016a,b; Gluskoter et al., 2009). The gangue minerals may oxidize in the waste piles or impoundments and dissolve into the water. Oxidation and/or dissolution reactions of different types of minerals such as sulfide, carbonate and clay minerals have been extensively researched (Bibi et al., 2011; Chandra and Gerson, 2010; Evangelou and Zhang, 1995; Huertas et al., 1998; Köhler et al., 2003; Moses et al., 1987; Pokrovsky et al., 2005). The dissolution of minerals in aqueous streams may result in pH variations and an elevation in total dissolved solids (TDS) in the supernatant water. The relative level of TDS concentration can be indirectly measured by the electrical conductivity (EC) of the liquid with higher values indicating an elevated TDS level.

* Corresponding author.

E-mail addresses: m.rezaee98@gmail.com (M. Rezaee), richard.warner@uky.edu (R.C. Warner), rick.honaker@uky.edu (R.Q. Honaker).

Specific conductance values of water exceeding 500 $\mu\text{S}/\text{cm}$ in headwater streams has been reported as one of the causes for the loss of certain groups of bugs, e.g. mayflies, and the disturbance of aquatic life in certain areas like Appalachia, USA (Cormier et al., 2011; Agouridis et al., 2012). To minimize the TDS and conductivity levels of the discharged water from the waste streams, identifying potentially high conductivity producing components followed by isolation or encapsulation have been suggested to be promising operational methods (Rezaee et al., 2013; Yeheyis et al., 2009). Given the vast number of mineral sources contained within typical mine wastes, a quick and inexpensive method for providing an initial ranking of the potential leachability is needed. The measurement of the water conductivity resulting from the contact with the solid waste meets the requirements assuming acceptable accuracy and precision. Using the conductivity test as a screening mechanism, the waste materials that have the greatest potential for environmental harm can be identified for isolation and the remaining material can be tested in more detail using established static and kinetic leaching tests to assure they meet environmental requirements (Chotpantarat, 2011; Kleinmann, 2000; O'Shay et al., 1990; Parbhakar-Fox and Lottermoser, 2015; Sobek et al., 1978).

To quickly assess and compare leachate geochemistry from historical metal mine dumps, Hageman (2007) developed the USGS Field Leach Test (FLT). In this test, 1000 mL of deionized water is slowly added to 50 g of prepared sample (20:1 water/solid ratio) in a wide-mouth plastic bottle. The capped bottle is vigorously hand shaken for 5 min and the contents allowed to settle for 10 min. The leachate is extracted from the bottle and analyzed for pH, specific conductance, alkalinity or other water quality characteristics. This test was later modified by Monday and Warner (2013) for screening-level specific conductivity of drill core strata in the field or laboratory. Modifications included a reduction from 1000 mL to 450 mL of either distilled or deionized (alternative methods) water with or without the addition of 50 mL hydrogen peroxide added to a 25 mg of sample (20:1 liquid/solid ratio) in a 1 L wide-mouth plastic bottle. Hydrogen peroxide and other oxidants increase the oxidation rate of minerals especially pyrite followed by dissolution of the elements. As a result, an expedited assessment of the leaching potential for mineral types and individual fractions of the mine waste can be achieved through the measurement of specific conductivity, and visual observation of effervescences (Holmes and Crundwell, 2000; Lara et al., 2015; Schoonen et al., 2010).

Previous researchers have found that parameters such as particle size and volume along with leachant volume are impactful parameters in assessing leachability using kinetic leaching experiments (Bradham and Caruccio, 1990, 1995; Brady and Weil, 2007; Kleinmann 2000; Sasaki, 1994). These parameters are directly linked to the exposure of the leachant to particle surface area (Lollar, 2005). However, the FLT and the modified FLT do not specify a particle size distribution. As such, the ratio of exposed surface area (SA) to the liquid volume is not held constant and, in fact, reaches values greater than 25:1. The impact is dilution of the ionic concentration which limits the ability to provide an initial leaching potential assessment using electrical conductivity measurements. Furthermore, the amount of oxidant (H_2O_2) added to the solution was not specified based on the mineralogical composition.

To develop a more meaningful standard test for rapidly performing conductivity screening assessments, the effects of three parameters and parameter interactions were evaluated using a statistically-designed test program. The parameters include: 1) surface area (as quantified by material particle size, density, and mineralogy of the sample), 2) volume-to-surface area ratio (VSAR)

and 3) the amount of oxidant. The parametric evaluation identified the appropriate test procedural modifications and quantities of solids, liquids and oxidants needed to ensure a precise and accurate evaluation.

2. Materials and methods

2.1. Sample collection and characterization

A representative sample of a coarse refuse stream from a coal processing plant treating Indiana 5-B central coal seam was collected. Coal from this source is characterized as high-volatile 'C' bituminous coal with high concentrations of organic and pyritic sulfur. Upon receiving the sample, the material was crushed using a laboratory jaw crusher to achieve a top size of 6.35 mm, which was selected based on the leaching test standard described by the D-5744 ASTM procedure. After crushing, the sample was split into 1 kg sample lots using a Jones riffler. The samples were placed into plastic containers and stored until needed in the test program.

Characterization of the coarse refuse was conducted on a representative 1 kg sample lot. As shown in Table 1, proximate, ultimate and sulfur form analyses found that the sample contained 54.5% ash-bearing material and the sulfur was primarily in the form of pyritic sulfur from which the oxidization product generates acidic runoff. The minerals present within the ash-forming material were identified and their content quantified using X-ray Diffraction (XRD) by the Rietveld method. The mineral was mostly pyrite which comprised 43% of the total material followed by nearly equal amounts of quartz, illite and kaolinite. A minor amount of calcite was also present which has value as a neutralizing component to counter acid generation. These findings were confirmed by results obtained from X-ray fluorescence (XRF) analysis of the ash produced by combusting the coarse refuse sample at 500 °C. The ash was primarily comprised of iron oxide which mostly resulted from the combustion of pyrite. Significant quantities of aluminum and silica oxides were found which was in agreement with the XRD results. A low CaO concentration indicated limited natural buffering capacity.

Prior to performing a modified conductivity screening test, a 1 kg sample was screened using sieves having 1 mm and 0.15 mm apertures which resulted in three particle size fractions: i.e., coarse (6.35×1 mm), fine (1×0.15 mm) and ultrafine (minus 0.15 mm). The ultrafine fraction was not used in the screening test and thus was discarded. The coarse and fine size fractions were subjected to density fractionation at a specific gravity of 2.95 using a lithium metatungstate (LMT) solution. In this process, the particle size fraction was submerged into an LMT medium contained in a 2-L beaker followed by removal of the float fraction using a screening tool which allowed the excess medium to drain. The remaining medium was filtered to recover the particles that settled to the bottom of the beaker. Both the float and sink fractions were rinsed and dried. As a result, four particle size and density fractionated samples were produced as shown in Table 2 which were used for the modified FLT parametric study.

Leaching characteristics of the bulk coal sample were studied by a static leaching test and a long-term dynamic column leaching test, which was performed according to standard ASTM method D-5744. The two long-term leaching tests were utilized to simulate various storage conditions associated with typical coal waste disposal practices. The static test was designed to simulate the stable storage of coarse waste materials submerged under water that are used for embankment construction of impoundments. The dynamic test was designed to model storage under more variable conditions similar to those of coarse refuse piles that provide intermittent exposure to air and variations in humidity.

Table 1
Sample characterization to quantify mineral composition.

Ultimate analysis (%)		Forms of sulfur (%)		Mineral (%) ^a (ash basis)		%Oxide (ash basis) ^b			
Ash	54.50	Total S	29.3	Pyrite	43	Al ₂ O ₃	10.41	K ₂ O	1.38
Moisture	1.60	Sulfate	1.1	Quartz	20	BaO	0.02	SiO ₂	24.41
C	17.90	Organic	7.6	Illite	19	CaO	0.45	Na ₂ O	0.24
H	1.60	Pyritic	20.7	Kaolinite	18	Fe ₂ O ₃	61.48	SrO	0.02
N	0.04			Calcite	<5	MgO	0.58	SO ₃	0.45
O	<0.01					P ₂ O ₅	0.15	TiO ₂	0.43

^a As %wt of mineral matter quantified using XRD analysis.

^b Major elements (ash basis) of the ash generated at 500 °C as quantified using XRF analysis.

Table 2
Four particle size and density fractionated samples.

Size distribution	2.95 float	2.95 sink
6.35 × 1 mm	Coarse-Float (CF)	Coarse-Sink (CS)
1 × 0.15 mm	Fine-Float (FF)	Fine-Sink (FS)

2.2. Conductivity screening test

As described in a previous section, the conductivity screening tests were conducted in accordance to the modified procedure described by Monday and Warner (2013). The exceptions were the particle size and density of the solids, solid mass, and the volumetric amount of de-ionized water and oxidant. In each experiment, a specified amount of solid sample was added to a volume of deionized water and oxidant in an appropriately sized container whose volume varied due to the evaluation of leachant volume-to-particle surface area ratio effect. The contents were mixed using a mechanical vibration device for a period of 15 min. After allowing 5 min for the sediments to settle, the electrical conductivity of the leachate was measured and recorded.

2.3. Parametric study

To quantify the importance of surface area and the interactive effects with particle size, a three-level statistically designed program was conducted which included several repeat tests to assess experimental error (Box and Draper, 1987; Gupta et al., 2016; Montgomery, 2012; Myers et al., 2009). Given that the effects may vary with mineralogy, a separate experimental program was conducted on two particle size fractions and two density fractions, as indicated in Table 2. A three-level test program based on the Box-Behnken statistical design was performed to evaluate the effects of surface area (SA), leachant volume-to-surface area ratio (VSAR) and amount of oxidant on the conductivity of leachates. The ranges of parameter values evaluated are shown in Table 3. The 20–80 cm² value range for surface area is typical for coarse refuse material. The volume-to-surface area ratio (VSAR) used in the original conductivity test was 25 cm³/cm² whereas the typical leaching column experiment utilized a ratio of 1 cm³/cm². The highest VSAR value was established to meet the symmetrical requirements of a three-level test design. The oxidant range was established based on a typical value of 15% and a general lack of quantitative data on the impact on conductivity.

Table 3
Parameter value ranges investigated in the Box–Behnken test program.

Parameter	Level		
	Low	Medium	High
SA (cm ²)	20	50	80
VSAR (cm ³ /cm ²)	1	25.5	50
Oxidant (%)	0	15	30

Surface area (SA) was calculated using the following expression.

$$SA = 6f \frac{m}{\rho \sqrt{(x_1 \times x_2)}} \quad (1)$$

in which SA is the surface area (cm²); *m* the weight of the material (g); ρ the solid density of the material (g/cm³); $(x_1 \times x_2)$ the geometric mean diameter of the material (cm); *x*₁ and *x*₂ bottom size and top size (cm) of the sample determined by sieve analysis; and *f* the shape factor, which is a function of the type and shape of the materials.

For example, a shape factor of 1 and 1.24 may be used for approximately spherical fly ash and cubic lime stone dust particles, respectively. For irregularly-shaped hydrated lime, a higher shape factor should be used. The values of shape factor for different types of materials ranges from 1 to 2, as shown in Table 4 (Craus and Ishai, 1977). A shape factor of 1.5 was applied for the studied material since the samples were crushed and thus not naturally occurring. Visual observations found that the crushed particles were not sphere nor cubically. Thus, a mean shape factor of 1.5 was selected to represent the characteristics of the crushed particles.

After calculation of equivalent mass of particles corresponding to the pre-determined SA, the required volume of deionized water to achieve the specified VSAR was added to the solids in a capped container. The samples were shaken for 15 min using a mechanical shaker and the conductivity of the leachates measured. For the three parameter evaluation, 12 tests with an additional five repeat tests at the central parameter values were conducted for each sample. A total number of 68 tests were conducted.

3. Results and discussion

3.1. Leaching characterization

To establish a baseline comparison, the leaching characteristics of the coarse reject and the corresponding leachate conductivity were evaluated using static and dynamic column leach tests. As shown in Fig. 1, the supernatant liquid pH was strongly acidic during the initial period of both the dynamic and static tests and remained acidic throughout the entirety of the tests. The lower acidic condition in the dynamic column leaching test was due to

Table 4
Particle shape factors for different materials used for the determination of surface area (Craus and Ishai, 1977).

Material	Shape factor (f)
Fly ash	1.00
Limestone	1.24
Hydrated lime	2.00
Glass beads	1.00
Dolomite	1.24
Basalt	1.24

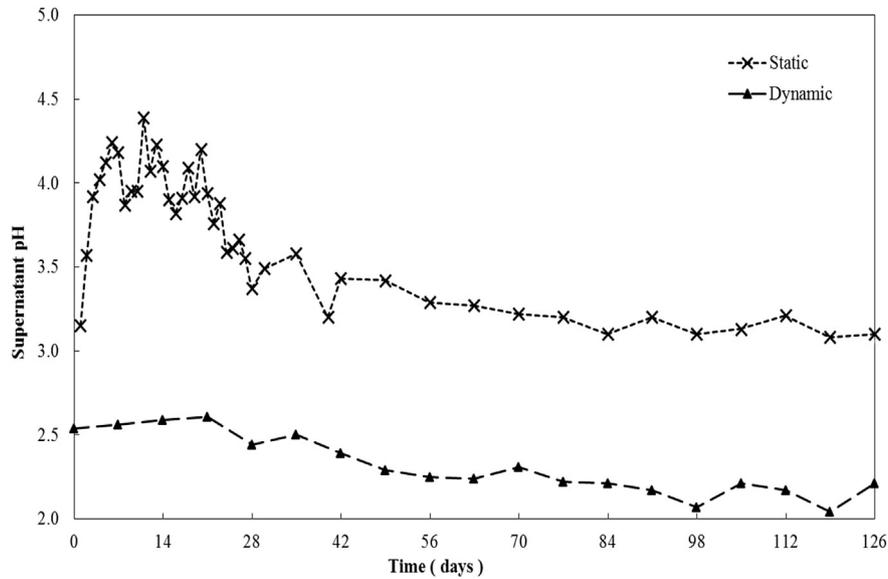


Fig. 1. Variation of supernatant liquid pH as a function of time in static and dynamic leaching tests conducted on the bulk coal sample.

the more aggressive oxidation as a result of weekly cycles of alternating periods of dry air (3 days), humid air (3 days), followed by leaching using de-ionized water on the seventh day. High pyrite content and a negligible amount of buffering capability (calcite content) in the sample were the primary reasons for the strong acidic medium when the sample was contacted with water.

Under these acidic conditions, a high amount of trace elements were released into the solution (Fig. 2), thereby increasing the conductivity level of the leachate. The electrical conductivity (EC) of the supernatant liquid collected from the dynamic column leach test was measured periodically throughout the duration of the test. The values trended downward after an initial high reading at around 14,000 $\mu\text{S}/\text{cm}$ to 6000 $\mu\text{S}/\text{cm}$. The conductivity of the leachate solution collected at the end of the static leaching test was also measured and the value of 7440 $\mu\text{S}/\text{cm}$ agrees well with the less aggressive conditions in the static test.

3.2. Statistical evaluations of conductivity populations

The test conditions and the EC values from the 68 conductivity screening level tests along with the average and standard error of repeat tests for each fraction are provided in Table 5. Seventeen tests were conducted on each of the four samples, i.e. fine-float, fine-sink, coarse-float and coarse-sink. EC values varied from 1 to 3530 $\mu\text{S}/\text{cm}$ and the variation was the greatest for the coarse-sink material which likely contained the highest amount of pyrite.

The initial statistical analysis focused on an assessment to determine if there are statistical differences in the population means using a one-way analysis of variance (ANOVA). The null hypothesis was that all population means were equal and the alternative hypothesis was that at least one mean was different. Based on a comparison between the F-statistic value of 6.07 and the value corresponding to a confidence interval level of 95%, the null

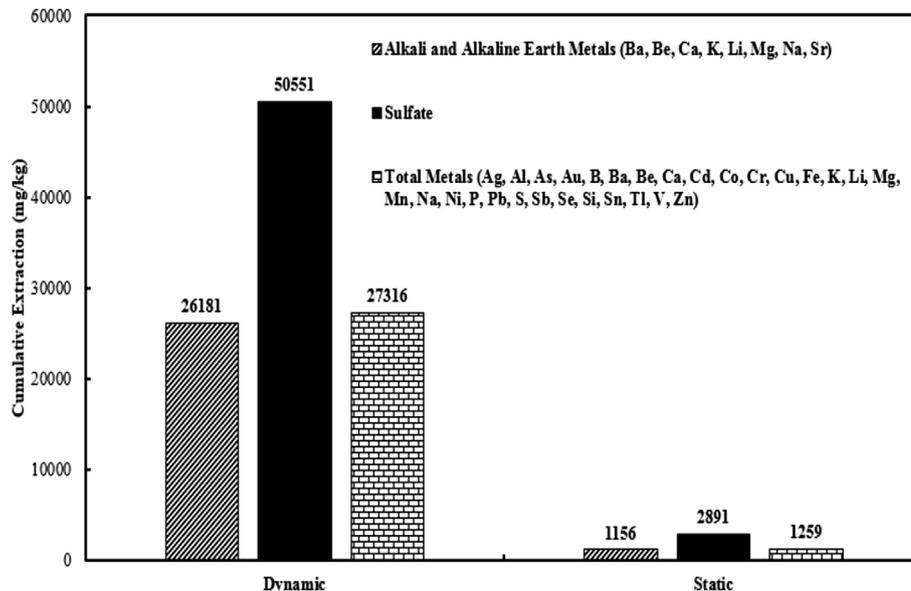


Fig. 2. Cumulative extraction of alkali and alkaline earth elements, sulfate and total metals from 1 kg of the coarse refuse sample in dynamic and static leaching tests.

Table 5
Summary of independent parameters and measured values for the response variable.

Trial no.	Parameters			Response Variables: EC ($\mu\text{S}/\text{cm}$)			
	S.A. (cm^2)	Vol.: S.A. ($\text{cm}^3:\text{cm}^2$)	Oxidant (%)	Fine-float	Fine-sink	Coarse-float	Coarse-sink
16	20	1	15	653	505	743	3480
8	80	1	15	487	828	643	1528
14	20	50	15	29	59	110	278
7	80	50	15	27	55	39	184
9	20	25.5	0	3	6	24	387
4	80	25.5	0	2	6	17	24
1	20	25.5	30	79	170	164	608
11	80	25.5	30	73	247	100	813
15	50	1	0	63	92	360	3450
17	50	50	0	1	4	6	205
2	50	1	30	722	1414	1106	3530
12	50	50	30	48	160	134	358
3	50	25.5	15	37	87	72	406
5	50	25.5	15	38	98	90	363
6	50	25.5	15	40	61	52	447
10	50	25.5	15	33	62	88	446
13	50	25.5	15	34	65	45	434
Average (Standard error) of repeat tests				36 (1)	75 (8)	69 (9)	419 (16)

hypothesis was rejected which meant that at least one of the population mean values was statistically different from the other three. This was the first indication that particle size and density have an impact on the EC values resulting from oxidation and contact with water.

As a result, a statistical analysis (matched-pairs *t*-test) was conducted to determine which group or groups among the four data sets have different population means. The analysis individually compared the mean of each population with each of the means of the other three populations. The null hypothesis in each case was that the pair of means was equal. The results of the analysis at a significance level (α) of 0.05 showed that the conductivity means (μ) of each size and density fraction are in the following order: μ fine-float < μ fine-sink \equiv μ coarse-float < μ coarse-sink. The findings indicate that the coarse-sink fraction is the primary source of the high conductivity values of the leachate from the overall coarse refuse stream in the long-term leaching experiments.

Given the specific gravity for pyrite of 4.8 relative to 2.9 or lower for most of the other minerals, the finding that the mean associated with the coarse-sink was different and higher than the other samples was understandable. The high conductivity level of this fraction is primarily due to the high amount of pyrite along with unliberated lighter minerals such as clay minerals. Although clay minerals are expected to be present in the float fractions, they may not be effectively separated in the density fractionation of the coarse materials due to lack of complete liberation. As a result, oxidation of the pyrite generates an acidic condition which not only releases associated calcophilic trace elements, but also dissolves lithophilic trace elements associated with the other mineral contents. On the other hand, the finding that the mean associated with the fine-float is different and less than the other fractions is simply due to the segregation of finely liberated less reactive minerals (such as clay minerals, quartz and organic matter) in this fraction.

This finding demonstrates the ability of the applied experimental approach to recognize and rank differences in conductivity level and identifying the fraction within a given waste stream that needs to be isolated to prevent negative impacts on the environment.

3.3. Parametric evaluation

To evaluate the parameter and parameter interactive effects,

empirical models were developed which were used to predict the electrical conductivity (EC) resulting from a combination of surface area (SA), volume-to-surface area ratio (VSAR) and oxidant addition values. Linear, quadratic and cubic models were considered. Linear models were found to provide statistically poor predictions for all four data sets while the cubic model significantly reduced the degrees of freedom and thus was considered unfavorable. The *p*-values obtained from ANOVA for quadratic models were less than 0.05 for four data sets, which indicates that the models are significant (Table 6).

The ability of the models to accurately estimate the response variable was measured by the coefficient of determination (R^2). The quadratic models for all the four samples were found to accurately predict the conductivity values as indicated by R^2 values greater than 0.9. To ensure that each model was not constrained by a low degree of freedom, the adjusted coefficient of determination (R^2_{adj}) was quantified for each data set. The differences were less than 0.033 for all of the four models derived in this study, thereby meeting the required standards to be accepted.

After acceptance of the models, the parametric and parameter interaction terms in each model were evaluated for their statistical significance. The null hypothesis used for the assessment was that the corresponding coefficient value was zero. Table 6 summarizes the test statistic values which represent the probability that the parameters or their associated interactions have no effect on the response variable. A prescreening of the parameters and interactions was conducted through rejection of any term having a *t*-value greater than 0.05 with exception of hierarchy conditions. The models were then modified according to the rejected terms. Table 6 provides the *t*-values for the remaining model terms established for each of the four data sets.

An observation of the significant model terms in Table 6 reveals that the most significant parameter affecting the leachate EC value is VSAR for all four materials while SA has no independent effect on conductivity. Fig. 3 also confirms that EC is a function of VSAR to the second order, and increasing the VSAR decreases the EC significantly due to dilution effect. The graphs in Fig. 3 were plotted at constant values SA and oxidant values of 50 cm^2 and 30%, respectively. However, the trends were independent of these values. Furthermore, a detailed analysis found that EC was not independently impacted by particle surface area (Rezaee, 2015).

Table 6
Statistical significance of the parameters and their associated interactions along with fit analysis for the models.

Fine-float		Fine-sink		Coarse-float		Coarse-sink	
Parameter	t-statistic	Parameter	t-statistic	Parameter	t-statistic	Parameter	t-statistic
Model	<0.0001	Model	<0.0001	Model	<0.0001	Model	<0.0001
B-Vol./S.A.	<0.0001	B-Vol./S.A.	<0.0001	B-Vol./S.A.	<0.0001	A-S.A.	0.0659
C-Oxidant	0.0037	C-Oxidant	0.0003	C-Oxidant	0.0002	B-Vol./S.A.	<0.0001
BC	0.0034	BC	0.0009	BC	0.0013	AB	0.0328
B ²	0.0002	B ²	0.0005	B ²	<0.0001	B ²	<0.0001
R-Squared	0.9039	R-Squared	0.9041	R-Squared	0.9578	R-Squared	0.9267
Adj R-Squared	0.8719	Adj R-Squared	0.8722	Adj R-Squared	0.9438	Adj R-Squared	0.9023

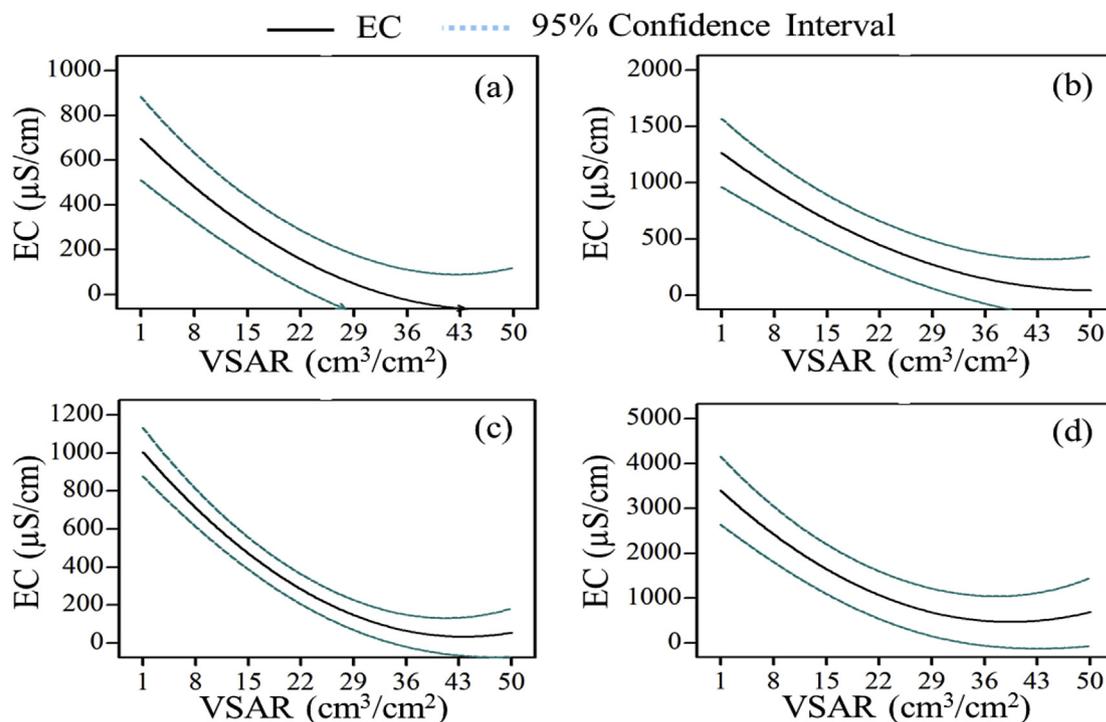


Fig. 3. Relation between EC and VSAR for different size-density fractionated samples: (a) Fine-Float, (b) Fine-Sink, (c) Coarse-Float, (d) Coarse-Sink.

Another significant parameters were the amount of oxidant and its interaction with the VSAR. Fig. 4 confirms the predicted significance of the oxidant percent on three of the four materials with the exception of the coarse-sink fraction. It is noted that the conductivity of the leachate from coarse-sink is already significantly high relative to the other materials. As described by the models and the graphs in Fig. 4, the variation of EC with percent of oxidant is linear for all materials except the coarse-sink fraction. The trends were independent of the selected other parameter values.

As noted, the interaction between the percent of oxidant and VSAR is significant and the interactive effect on EC is shown in Fig. 5. As shown, VSAR has a significantly greater impact than the amount of oxidant on EC. Depending on the sample mineralogy and TDS value after a given dilution ratio, the EC of the supernatant water significantly decreases. This observation is consistent with the dependency of EC with the second order of VSAR in the developed quadratic models.

An additional observation from Fig. 5 is that a 1:1 VSAR for all four fractions results in an elevated conductivity level even without the use of an oxidant, which simplifies the conductivity screening test. As a result, one may consider just using a 1:1 VSAR in the conductivity screening test and eliminate using the oxidant since hydrogen peroxide is not naturally available during dissolution of

minerals in a mining environment. This 1:1 VSAR value is also more representative of the mining environment, and is also commonly used in soil testing as suggested by a number of researchers for implementation in leaching columns and weathering cells (Kleinmann, 2000).

3.4. Modified conductivity test procedure

Understanding the effects of the parameters facilitated modification of the standard Field Leaching Test. Based on the parametric analysis, it is recommended to modify the standard conductivity test procedure as described as follows:

- 1 Particle size analysis of a representative sample by sieving to determine the top and bottom size of the material;
- 2 Measure solid density;
- 3 Calculate surface area using Eq. (1);
- 4 Add distilled or deionized water to the sample at a volume that provides a volume to surface area ratio (VSAR) of 1:1 (cm^3/cm^2);
- 5 Shake the capped container for 15 min;
- 6 Measure conductivity of the leachate after allowing particles time to settle. The leachate may be filtered for further analyses.

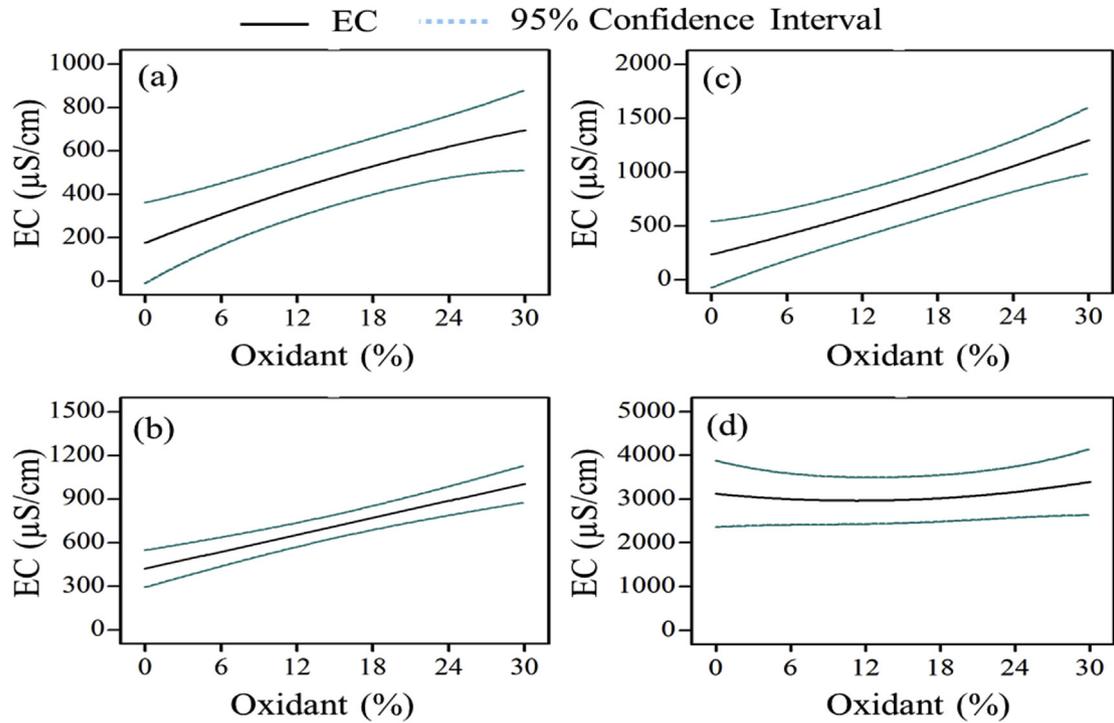


Fig. 4. Relation between EC and oxidant for different size-density fractionated samples: (a) Fine-Float, (b) Fine-Sink, (c) Coarse-Float, (d) Coarse-Sink; VSAR = 1 cm³/cm² and SA = 50 cm².

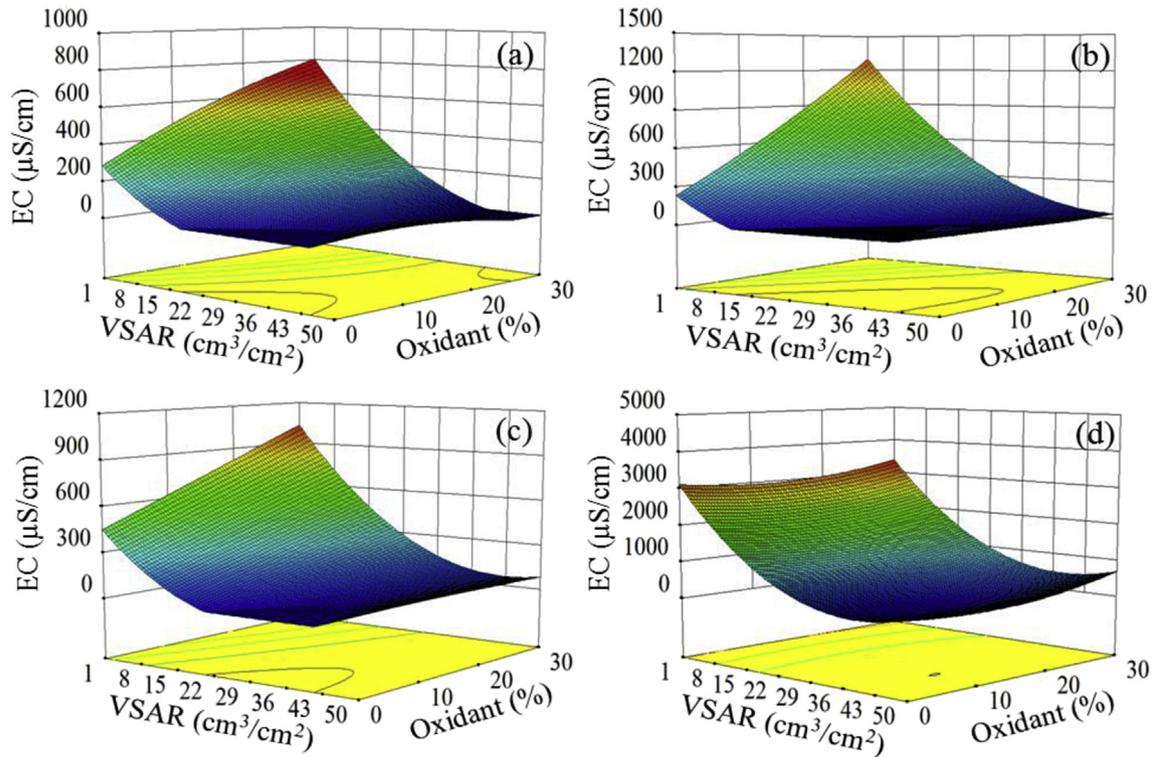


Fig. 5. Predicted interactive effects of VSAR and oxidant on EC for different size-density fractionated samples: (a) Fine-Float, (b) Fine-Sink, (c) Coarse-Float, (d) Coarse-Sink.

To simplify the process, the test can be conducted by determining the amount of solids mass needed in 1000 mL of deionized water to realize a VSAR:SA ratio of 1:1 based on an effective surface area of 1000 cm². Using this approach, the conductivity screening

test then can be easily applied as an adequate and quick procedure as a first step in evaluating the leaching potential of different particle streams and associated fractions within the streams as shown in Fig. 6. The materials can be ranked based on the leaching

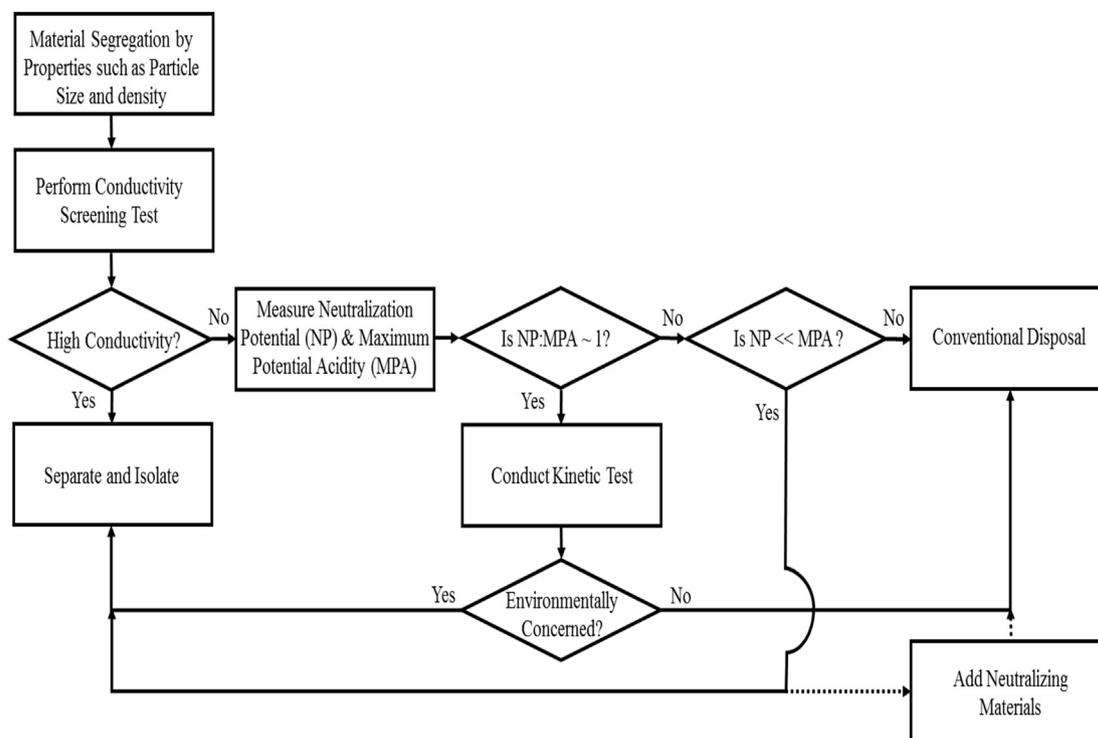


Fig. 6. Decision making procedure for the disposal of waste streams.

potential to provide an effective decision making process for particle-particle separation followed by isolation of the environmentally concerned fractions.

4. Conclusions

Oxidation and dissolution of the mineral content comprised in processing waste streams results in the release of major and trace elements thereby causing an elevation of electrical conductivity of the water in contact with the materials. Identification and separation followed by isolation/encapsulation of the fractions causing the elevation of TDS and conductivity of water may minimize the environmental impacts of waste disposals. To achieve this goal, an accurate conductivity screening test that can provide a timely assessment of the various components in a waste stream is needed.

Understanding the effect that the various parameters have on the conductivity of the water in contact with the solid surfaces is necessary for developing an adequate conductivity test. Particle surface area, liquid volume-to-particles surface area ratio and the amount of oxidant were identified as key parameters impacting electrical conductivity of the leachate. The effects of the parameters were quantified using data obtained from a test program that was conducted based on a statistical three-level design known as the Box-Behnken method. Separate test programs were conducted on two different particle size fractions and density fractions from a coarse coal waste material which effectively varied the mineralogical composition. A statistical analysis of the test results indicated that the coarse and high density fraction provided supernatant liquid conductivity values that were significantly different than those obtained from the coarse-low density material and the high and low density fractions of the small particle size fraction. This finding is likely due to the high pyrite content in the heavy fraction along with unliberated clay minerals and low concentration of minerals like calcite that could provide neutralizing potential.

Quadratic models were developed using the parametric test results. Based on a statistical analysis of the models, the significance of the parameter and parameter interactions followed the order of 1) liquid volume-to-solid surface area ratio (VSAR), 2) oxidant amount and its interaction with VSAR, and 3) the interaction between VSAR and surface area. Surface area was not found to be an independently significant parameter for all four material cases. A low VSAR value of 1:1 produced an elevated supernatant conductivity value in all cases which facilitates the decision making process for identifying materials and/or components requiring additional investigations or isolation for waste storage. Based on the findings of the parametric study and subsequent statistical analyses, a modification to the existing standard conductivity screening test was developed.

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