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The Effect of Pulp Potential and Surface Products on Copper Mineral Flotation

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A Thesis Submitted to the Faculty of Graduate Studies and Research

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Abstract

The effect of pulp potential on the recovery of copper, lead, zinc and iron from the ore of Kidd Creek Mines (Timmins, Ontario) was examined. Air and nitrogen as flotation gases were compared for their effect on the metallurgical response (recovery and the separation efficiency of Cu/Zn and Cu/Fe).

The extraction of metal cations from the mineral surface in-situ by EDTA at varying pulp potentials and with various reagent schemes was performed, and the differences in extraction from concentrates and tailings was examined. The effect of aeration on the extraction of cations Cu,Pb,Zn and Fe was analysed as well as its effect on dissolved oxygen (Dynamic Dissolved Oxygen). Plant surveys of pulp potential, pH and extraction by EDTA are compared to laboratory values.

The optimum pulp potential for the recovery of copper with no collector addition was -50 mV (vs Ag/AgCl). Collector increased the range of pulp potential where maximum copper recovery could be achieved. The maximum separation efficiency between copper/zinc and copper/iron was approximately -230mV and -50mV, respectively.

Copper was not extracted by EDTA, possibly due to its incorporation in the lattice of pyrite and sphalerite. The extraction of iron, zinc, and lead from the feed decreased with increased aeration, and was not strongly affected by the addition of SO_2, lime or collector.

The factors Em and Es (mg metal per gram of solid and mg of metal per gram of metal, respectively) were developed to analyse the data obtained. The differences in the extraction of iron between tails and concentrates was strongly related to the separation efficiency.

Extractions at specific pulp potentials were found to be similar between the plant and laboratory.

Resumé

L'effet du potentiel de la pulpe a été etudié sur les recuperations de cuivre, plomb, zinc et fer de Kidd Creek Mines (Timmins, Ontario). L'air et l'azote en tant que gaz de flotation ont éte comparés pour leurs effets sur la réponse metalurgique (efficience de la recuperation et separation de Cu/Zn et Cu/Fe).

L'extraction des cations de metal de la surface des minerais in situ par EDTA fut realisée a differents potentiels de pulpe et avec differents schemas de reactifs et on éxamina les differences d'extraction des concentrés et des rejets. L'effet de l'aération sur l'extraction de cations de Cu, Pb, Zn et Fe fut également analisé ainsi que ses effets sur de l'oxygène dissout (Dynamic Dissolved Oxygen). Mesures en plante du potentiel de la pulpe, du pH et des extraction par EDTA ont été comparés aux valeurs au niveau de laboratoire.

Le potentiel de pulpe optimum pour le cas de recuperation de cuivre sans addition de collecteur fut de -50 mV. Le collecteur augmenta le rang de potentiel de pulpe là où une recuperation máximale de cuivre pouvait s'atteindre. L'efficience de la separation cuivre/zinc et cuivre/fer fut de -230mV et -50mV, respectivement

Le cuivre en fut pas extrait du EDTA, possiblement dû a sa forte adsorption dans les estructures de pirite et sphalerite. L'extraction de fer, zinc et plomb de l'alimentation diminua avec une augmentation de l'aération, cependant elle en fut pas affectée par l'addition de SO_2, chaux et collecteur. Les facteurs Em et Es (mg de metal par gramme de solide et mg de metal par gramme de metal, respectivement) furent developpés pour l'analyse des données obtenues. Les differences dans l'extraction de fer entre rejets et concentrés furent fortement liés a l'efficience de la separation. Extraction a des potentiels de pulpe spécifiques ont éte similaires entre la plante et le laboratoire.

Acknowlegements

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1.0 Introduction

> *"Mineral Flotation is undoubtedly the most important and versatile mineral-processing technique, and both use and application are being expanded to treat greater tonnages and to cover new areas."*
>
> (Wills, p.457)

Mineral flotation is achieved through the selective adhesion of selected mineral particles contained in an aqueous mixture to gas bubbles. The objective, then, is to render selected minerals hydrophobic (water repellent) so that they may be concentrated and further processed economically, having removed the majority of impurities (or gangue minerals). The mechanism of this adhesion, and hence the mechanism of the process, is as yet not completely understood (Wills, 1988), although several theories exist. The chemistry of the system is difficult to characterise for two reasons: (1) the large quantity of species in solution derived from the dissolution of some minerals, water impurities, and reagent additions and (2) the inability (at present) of examining species present upon the mineral surface in-situ (Chander, 1985).

The lack of knowledge of the mineral surface and its interaction with the aqueous medium, the gas phase, and other mineral surfaces has constrained flotation research (and therefore industrial progress) in a number of ways: the development of collectors (reagents specifically designed to promote hydrophobicity of the mineral surface) with increased selectivity against gangue minerals; the development of real-time monitoring systems to characterise the reagent requirements of different ore zones within an orebody; and the development of reagent schemes with more than empirical knowledge as a reference. At present, flotation concentrators rely on the measurement of metal values in various streams to monitor reagent scheme effectiveness. This information then, provides for "feed-back" control. If an unscheduled ore change occurs, the resulting reagent scheme changes are made only after the ore change has occurred and with empirical knowledge as a basis. This can be an inefficient process if feed changes are frequent and drastic, and can lead to losses in grade and recovery. In order for control systems to fully attain their potential in flotation plants, the process must be better characterised.

Much flotation research has been aimed at the characterisation of the flotation response based on bulk parameters such as grade, yield, recovery, and the effect that different reagent schemes have on these parameters. The determination of the pulp chemistry, however, could lead to a more fundamental understanding of the flotation process. Determination of the bulk chemistry within the flotation pulp would then be the precursor to surface chemistry analysis, and the next stage in correlating pulp chemistry to flotation.

The "character" of the mineral surface (amount and stability of surface products, oxidation state) at the time of capture by a bubble is clearly an important variable in the investigation of flotation. As sulphide minerals consume oxygen in the pulp, the nature of their surfaces evolves. Reagent additions also alter the surfaces. The influence of reaction products, precipitates and absorbed species have long been used to explain discrepancies in the flotation of the same mineral (Senior, 1991; Acar, 1992; Hayes, 1987; Gaudin, 1957). These oxidation products (the mixture of hydroxides, oxy-hydroxides, hydrous oxides, etc.) are often collectively called hydroxides. As an example, Senior and Trahar (1991) have stated that the lack of "self-induced flotability" in minerals is due, in part, to the oxidation products on their surface. However, the state of the surface in real-time is as yet unavailable.

Instruments continue to be developed to probe surfaces. A scanning electron microscope (SEM) is available which allows for water vapour to be added to the SEM's sample chamber, and therefore the evolution of surface species can be examined under conditions more closely related to those in practice (Rao et al., 1992). X-Ray photo-electron spectroscopy (XPS) (Smart, 1991) and laser induced mass spectroscopy (LIMS) (Chyssoulis et al., 1992) are examples of methods which allow for the characterisation of a mineral surface. However, these methods are time consuming as the characterisation of the surface is performed for each particle individually. Also, these methods involve the extraction of a sample from the process stream. Removing a sample leads to inherent bias as the evolution of surface species continues and it is difficult to gauge the effect that drying and sample preparation will have on the surface. The ideal method of determining surface characteristics would therefore be in-situ (i.e. within the process stream itself).

As an on-line surface characterisation process has yet to be engineered, research into pulp chemistry continues in a two-pronged approach. First, to isolate the chemical processes occurring within the pulp (single reagent, single mineral studies), and secondly to use "measures" that can be correlated to flotation response and attempt to backtrack to their origins (Chander, 1985). These "measures" or bulk parameters include: pH, Ep (electrochemical potential of the pulp, or pulp potential), and dissolved oxygen measurements, as well as a method for determining metal cations present on the surface of mineral particles which is the focus of this thesis.

Pulp pH has been monitored for decades and is used empirically. For example, it is well-known that pH levels greater than 11.0 will usually effectively depress pyrite. However, in certain orebodies, pH levels of greater than 11.5 are required, while in others, pH levels of 10.0 are sufficient. This is usually attributed to the level of "activity" of pyrite, or its propensity to float. The pH level is also dependent on the reagent scheme and type and amount of collector used (Wills, 1988). The actual mechanism of the depression is not known for certain, although it is assumed to be the adsorption of calcium ions (or calcium salts) and iron hyroxides on the negatively charged surface of pyrite (Weiss, 1985). The adsorbed species then reduce the adsorption of xanthate. While pH is the parameter monitored, the reagent used to achieve the pH level is also of importance. From the above example, lime (CaO), sodium hydroxide (NaOH) or soda ash (Na_2CO_3)could be used to achieve the required pH level of 11.0. The flotation response, however, is not usually the same. The addition of large amounts of lime in a pulp high in dissolved metal cations can cause an increase in viscosity as precipitates are formed. Also, as previously mentioned, the calcium ion can effect selectivity through its interaction with the surface of pyrite. pH is not, therefore, an absolute indication of pulp chemistry as hydroxyl interactions with metal ions in solution as well as the type of pH modifier will affect the flotation response. While pH was monitored during the course of this study, its impact on metallurgical response was not investigated.

The first parameter evaluated in this study is pulp potential which is in the early stages of development as a control parameter in flotation. It is monitored in several plants although not generally used as a control parameter in base metal flotation. It is used for the control of the addition of such reagents as sodium sulphide and sodium hydrosulphide for the sulphidisation of oxide minerals, and for the addition of sodium cyanide, sodium hydrosulphide, and Nokes reagent in the depression of copper sulphides for their separation from molybdenite (Adams, 1989). In the latter case, the reduction in pulp potential acts to desorb collector from the surface of chalcopyrite. In fact, nitrogen is sometimes used as the flotation gas to maintain a low pulp potential . The use of air as a flotation gas tends to increase the pulp potential allowing for the re-adsorption of collector (Wills, 1988). Pulp potential can therefore be used in an attempt to define the oxidising or reducing power of a flotation pulp.

Oxygen demand is another parameter used to measure the extent of oxidation (Spira et al., 1974). The rate of decrease of oxygen in a system when aeration ceases is a measure of the affinity of the minerals to consume oxygen. A mineral surface should become less reactive to oxygen as the demand is fulfilled. This then is the second bulk parameter monitored and correlated to metallurgical response during the course of this thesis.

Another method of measuring the extent of oxidation of the system is extraction of surface species through the addition of a strong complexing agent such as EDTA. This chemical is used as it is relatively inert to metal sulphides, but reacts strongly with less stable compounds (Senior et al., 1991). Numerous researchers have investigated the solubility of sulphide minerals in EDTA solutions, and have reported that while the dissolution of surface oxide products occurs rapidly, the dissolution of the remaining sulphide matrix is slow (Greet et al., 1994). If the contact time is therefore kept to a minimum, EDTA extraction should only relate to the degree of oxidation of the mineral's surface. Shannon and Trahar (1986) have shown qualitatively that the role of metal ions was not in the prevention of the formation of a hydrophobic layer (e.g. by reaction with collector), but rather in the creation of a hydrophilic layer on the mineral surface. Their research centered on the use of EDTA as a complexant in order to rid the surface of these interfering products. In this thesis the objective is to measure the amounts of metal ions which are stripped from the surface, to compare this value to either aeration time or pulp potential, and to analyse correlations to flotation response.

As the true meaning of the pulp potential measurement has been questioned by some researchers it is hoped that EDTA extraction, through its ability to suggest ionic species on the surface, might provide a start to modelling the electrochemistry of the system when used in conjunction with other surface analysis techniques.

By comparing oxygen demand , pulp potential and the types and amounts of cations on the surface of the mineral particles, an increased understanding of mineral flotation systems is sought. In addition, it is hoped that by exploiting the EDTA extraction technique, new avenues of investigation will be revealed.

2.0 Project Objectives

The primary objective of the project was the determination of the optimum pulp potential range for copper/zinc selectivity. In order to produce this data, laboratory batch flotation tests were performed at various pulp potential levels with several reagent schemes.

This data was supplemented by a correlation of extractable metals to metallurgical response and pulp potential. Plant surveys of pH, pulp potential and EDTA extraction were performed at Kidd Creek Mines in order to compare with laboratory data. The measurement of the Dynamic Dissolved Oxygen (DDO) in laboratory testwork was performed as a supplement to this work.

The ore tested was from Falconbridge's Kidd Creek division. The Kidd Creek concentrator is located in Timmins, Ontario, Canada. The concentrator treats a complex sulphide orebody consisting of massive chalcopyrite, sphalerite and pyrite and produces copper and zinc concentrates (see Figure 1). Relatively fine grinding (50% -325 mesh or 45μm) is required due to the small grain size. Improving copper/zinc selectivity is an ongoing project in the copper circuit.

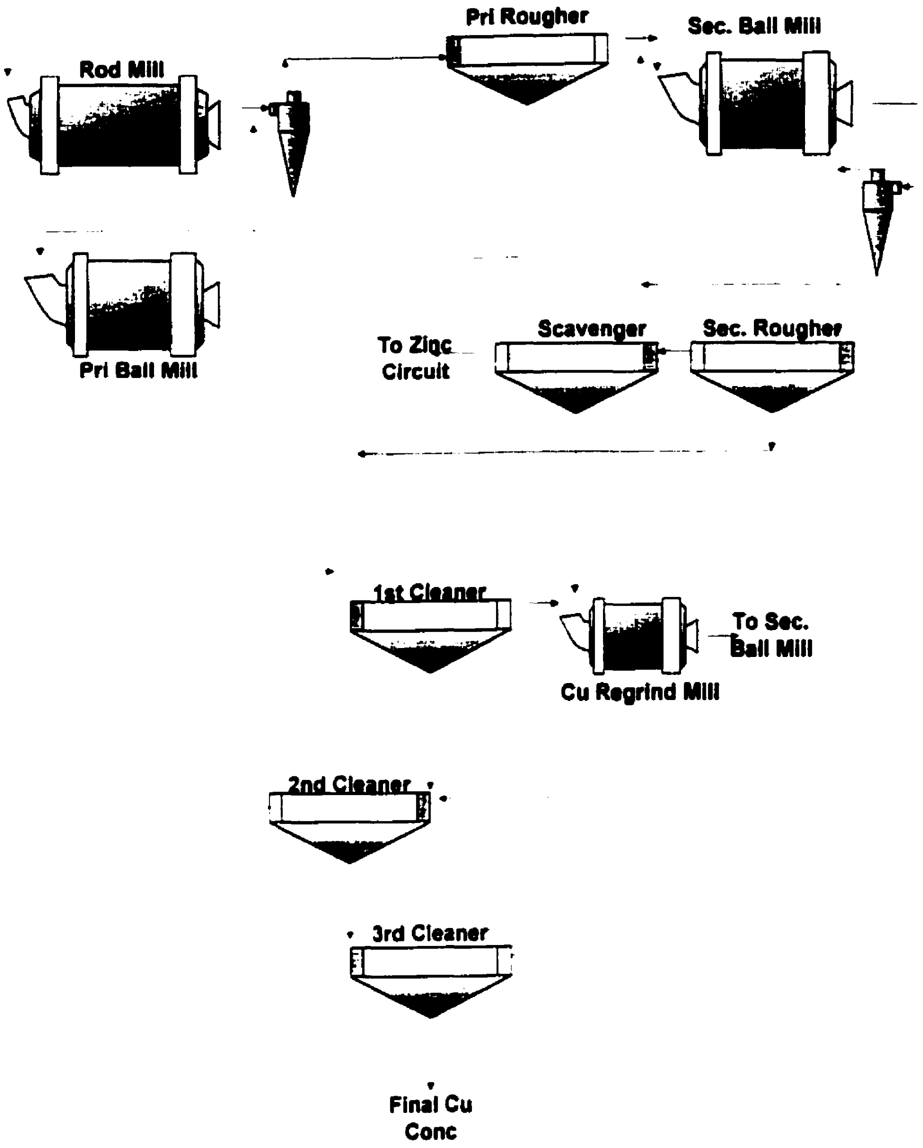

Figure 1. Kidd Creek Flowsheet

3.0 Literature Review

3.1 Electrochemical Theory

3.1.1 Simple Solutions

Electrochemical potential is a measure of the tendency of charge transfer reactions to occur. At standard conditions, the measurement of the potential is characteristic of the species within the solution.

The inability to measure the potential of one charge transfer reaction has led to the need for standard reference electrodes. The standard hydrogen electrode (SHE) has a potential of 0.0 millivolts by convention (at 25 °C). Electrochemical data are usually reported against the SHE as E_h, however the more convenient silver/silver chloride or calomel electrodes are more commonly used for measurement (Davis et al., 1984). Sensing electrodes (see *3.1.5 Electrode Selection*) are usually of noble metals due to their resistance to corrosion and good electrical conductivity.

When the electrode pair (reference and sensing) are submerged in a solution at equilibrium, the rest potential of the reaction is measured.

This can be calculated from the Nernst Equation:

$$E = E^{\circ} - (RT/nF)\ \ln \{a_{reduced}/a_{oxidised}\}$$

where:

n = no. of electrons transferred in the half reaction

R = Gas Constant (8.314 J/mol•K)

T = Temperature (Absolute Temp., °K)

F = Faraday Constant (96 487 J/V•mol electron)

a = activity of species (mol/litre)

This implies that along with the concentrations of the species participating in the reactions, E is also dependent on temperature and is usually tabulated at 25°C (Davis et al., 1984).

The electrochemical potential is also related to Gibbs free energy change ΔG. ΔG can be thought of as the maximum electrical work which can be derived from the oxidation/reduction reaction (Davis et al., 1984). The relation is given by:

$$\Delta G = -nFE$$

The larger the potential of a solution, the greater its tendency to act as an oxidiser. However, these values do not give any information pertaining to rates of reaction , only to the potential for the reaction to take place.

3.1.2 The Mixed Potential Theory

The electrochemical theory of flotation, first proposed by Polish researchers in the 1930's (Kamienski, 1931; Kamienski et al., 1954; Pomianowski et al., 1974), is derived from the electrochemical theory of corrosion (Poling, 1976). This theory assumes that the sum of the rates of all oxidation and reduction reactions must be equal for electrical neutrality to exist. In the simplest case the mineral particle adopts a single "mixed potential" value across its surface. This "mixed potential" is between those of the two reversible reactions. Since anode sites sweep across the surface as dissolution occurs and, because of the conductivity of metals (and sulphide minerals), potential differences cannot be maintained at the surface, the entire surface will be at this "mixed potential".

3.1.3 Mixed Potential Model

When two oxidation/reduction couples are present in equilibrium in solution, the electrochemical potential theory still applies. The solution will adopt one single potential such that:

$$E_h\ (ox_1 / red_1) = (ox_2 / red_2)$$

There will be no net electron flow between the couples, but they may not be separated since electrons still pass from one couple to another and back.

However if the two couples are not in equilibrium, i.e.:

$$E_h\ (ox_1 / red_1) \neq (ox_2 / red_2)$$

then an immersed electrode can pass electrons to either reaction pair preferentially. The measured potential will be that where the anodic and cathodic reactions of reaction$_1$ and reaction$_2$, respectively, proceed at the same rate (see Figure 2) (Rand et al., 1984).

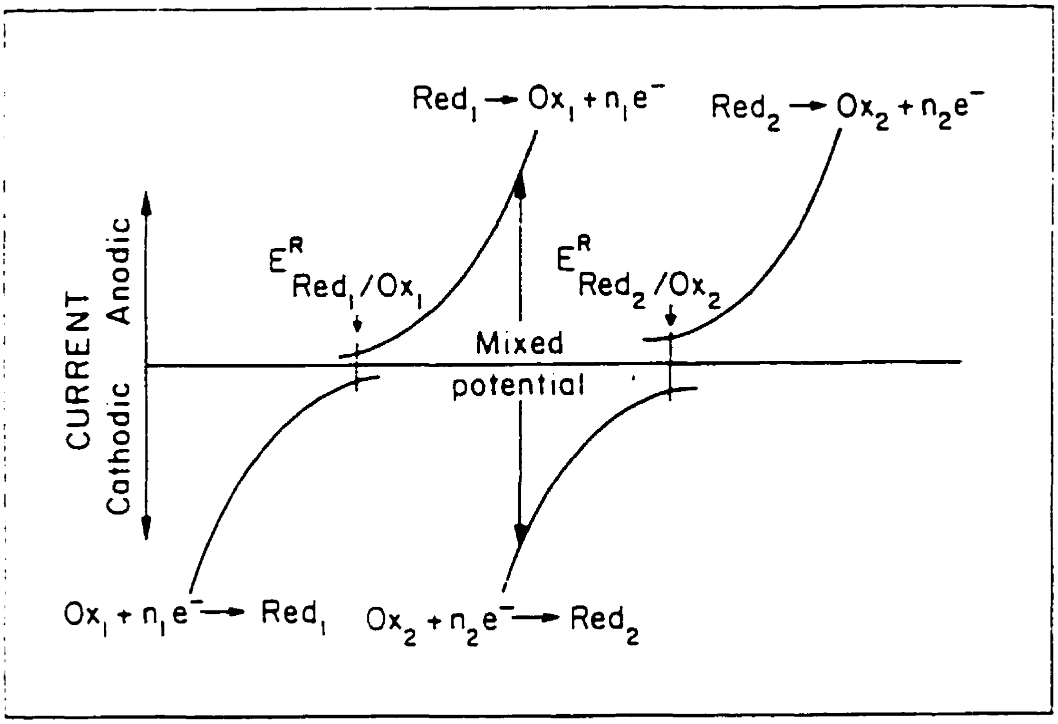

Figure 2 Schematic Representation of the Mixed Potential System

(from Rand and Woods, 1984)

The continued effort to increase flotation efficiency has led to the development and use of electrochemical concepts in slurry systems. The electrochemical approach to controlling flotation is based on the premise that charge transfer reactions govern the success of the production of a hydrophobic film on the mineral surface. Collector/sulphide mineral reactions are assumed to take place via reactions which involve:

- the anodic oxidation of collector
- the cathodic reduction of oxygen

The rate of these reactions can be inferred from the potential difference across the mineral/solution interface, and from this (according to the electrochemical theory), the flotation response is dictated (Rand et al., 1984).Application of this theory to flotation and, in particular, thiol collector adsorption, leads to two possible reactions:

(1) Cathodic Reduction of Oxygen

$\frac{1}{2} O_2 + H_2O + 2e^- = 2OH^-$

(2) Anodic Oxidation of Xanthate

$2ROCS^{2-} = (ROCS2)_2 + 2e^-$

(where $(ROCS_2)_2$ is dixanthogen)

In order for dixanthogen to form, the "mixed" or rest potential must be anodic to the equilibrium potential of xanthate (Allison et al., 1972). However, the reduction of oxygen at the mineral surface does not necessarily lead to the formation of dixanthogen (Salamy et al., 1953; Gardner et al., 1973). Other oxidation reactions are possible, such as:

$$Me_2S + 2X^- \rightarrow 2MeX + S^\circ + 2e^-$$

$$Me_2S + O_2 + 2X^- \rightarrow 2MeX + S_xO_4^{=} + 2e^-$$

It has been shown (Plaskin, 1957; Eadington et al., 1969; Fleming et al., 1965) that some minerals do not adopt a single mixed potential across their surface. Instead, differences of several hundred millivolts have been recorded at different sites on the surface of a mineral particle. Thiol collectors appeared to adsorb more readily on anodic sites, but the electron transfer appeared localised at that spot, and the sites became increasingly cathodic with increased xanthate adsorption. The amount of reduction did not necessarily compensate for the electron transfer, which may imply that other reactions were taking place simultaneously at the surface.

Another assumption of the corrosion/mixed potential theory states that reduction and oxidation reactions must proceed at the same rate. However, if the dissolution of minerals (and the subsequent production of an electrical double layer) is taken into account, then some electron charge transfer could be accommodated within the double layer. Therefore, the sum of reduction reactions might not equal the sum of oxidation reactions, and the mixed potential theory would not apply (Poling, 1976).

These differing and at times contradictory theories of the potential of the surface highlight the controversy surrounding the use of pulp potential. The impact of pulp potential on the surface of a mineral and therefore its amenability to collector adhesion has yet to be characterised in a complex system, and certainly, an overall theory which encompasses all mineral types in slurry systems has yet to be proposed.

3.1.4 *Method of Pulp Potential Control*

There are two methods of pulp potential control available, namely potentiostatic and chemical.

Potentiostatic control involves the application of an external potential on the mineral slurry. This is the easiest method of obtaining consistent pulp potentials and is therefore commonly used in laboratory work (Kirjavainen et al., 1992; Woods, 1976; Guy et al., 1985; Trahar, 1983).

However, there are as yet several engineering difficulties to be surmounted in the implementation of potentiostatic control of pulp potential (Rao et al., 1992) such as designing the reactors necessary, the safe use of the power required and correlating the current density to the surface density of mineral particles (particularly difficult as the specific surface areas (m^2/g) are rarely reported). It was therefore decided to use a chemical method of control in the experiments reported in this thesis. This requires the use of chemical reagents to modify the pulp potential. It is desirable that these reagents do not modify other important aspects of the pulp chemistry which might affect flotation. Heyes and Trahar (1977) have done work in this area, and have seen no significant difference in flotation when air/nitrogen were used as modifiers as opposed to peroxide/sodium dithionate at equivalent potentials. Other reports have shown a shift in the recovery/potential curve (Rohner, 1989). It was decided that an air/nitrogen system would be used for the control of pulp potential. This system is a practical one for plant applications, not requiring the purchase of specific reagents or reagent handling systems.

3.1.5 Electrode Selection

As previously mentioned, noble metals are chosen as the sensing electrode. However, the use of noble metals was the result of a transfer of technology from the chemical industry which had used electrochemical potential in many applications previous to its adoption in mineral processing (Glasstone, 1942).

In fact the convention was (and is) to use black platinum electrodes. These are smooth platinum electrodes which are then finely coated with a layer of finely disseminated platinum black. This creates a large surface area for potential measurements. However, as noted by Glasstone (1942):

> *In some cases the very properties which make the platinized platinum electrodes satisfactory for the reduction of polarisation are a disadvantage. The finely-divided platinum may catalyse the oxidation of organic compounds, or it may adsorb appreciable quantities of the solute present in the electrolyte and so alter its concentration (pp.35-36).*

Rand and Woods (1984) have performed experiments comparing the potentials measured by gold and platinum. Figure 3 shows the Eh measured in a Fe(II)/Fe(III) system by gold and platinum electrodes with and without oxygen present.

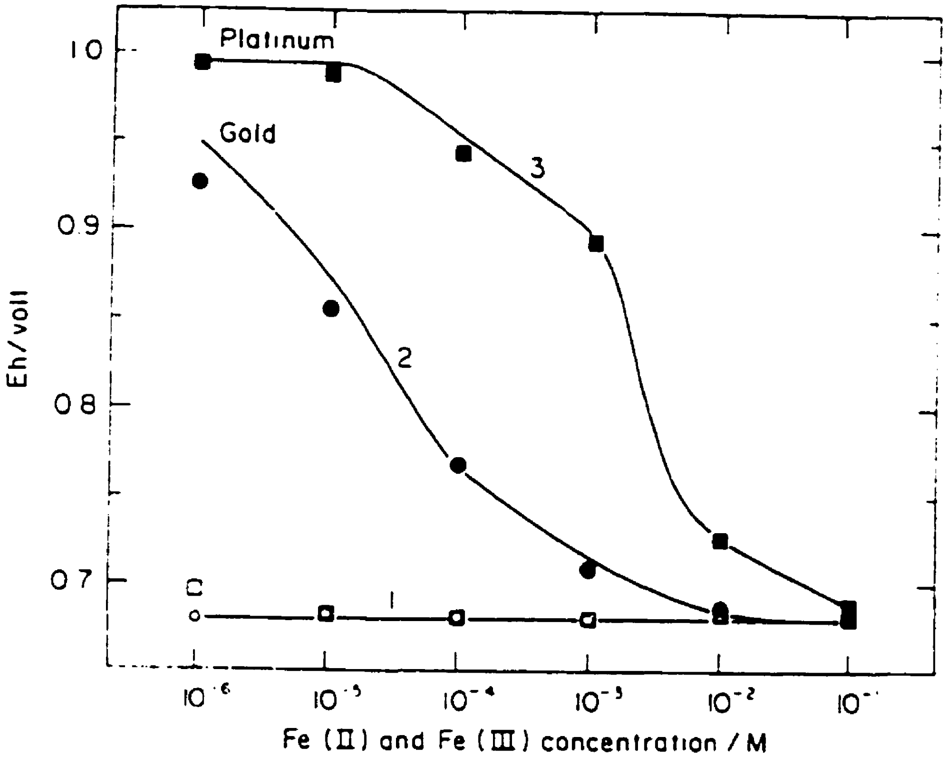

Figure 3. Variation of Electrode Potential with Iron Concentration

(from Rand and Woods, 1984)

When oxygen is present, potentials vary from the reversible iron couple. Platinum, in fact, differs more than gold because the reactions have different reversible potentials and therefore the potential which is measured is a mixed one. This implies that the rate of reaction at the electrode surface will affect the pulp potential reading, and therefore the rate at which an electrode adsorbs species will become the determining factor in potential measurements. It has been suggested that platinum is not an "inert" electrode (Natarajan et al., 1974), but this depends upon the definition of inert. While platinum does not react, it can act as a catalyser for reactions, increasing their rate, and therefore can inflate potential values. Rand and Woods (1984) have suggested that gold might be a better electrode material since it reacts more quickly to process changes and approximates mineral electrode potentials (especially that of chalcopyrite).

For the study of mineral reactions (surface reactions), the use of mineral electrodes would seem to be the obvious choice (Avdokhin et al., 1989).

The mineral electrodes can be solid minerals set in resin where electrical contact is made through a mercury drop to a copper wire. Also, packed mineral particle bed electrodes (Hayes, 1987) have been used to monitor reactions under varying concentration of reagents or pulp potential.

The sulphide mineral electrode has the advantage of monitoring the potential of the same mineral in the pulp phase. In this way, any reaction occurring at the surface of these particles should be detected by the electrode. There are disadvantages, however. Firstly, if a non-reversible reaction takes place at the electrode surface, removal of the surface product would require the withdrawal of the electrode from the slurry. Also, the mineral pieces used for these electrodes must be essentially pure. Impurities will cause large variations in impedance and therefore the potential measured. It is for these reasons that noble metal electrodes are more commonly used industrially.

In summary, when a mixed potential is to be measured of a complex sulphide flotation slurry it is perhaps gold that should be chosen as the sensing electrode. If it is the reactions occurring at the surface of particular minerals that is to be monitored, mineral electrodes would be the choice. Gold was chosen for the set of laboratory experiments since a bulk measurement of potential was desired. It was not the objective of this study to follow the pulp potential of one mineral, but rather to gauge the effect that a slurry pulp potential had on the surface of all minerals in the pulp. A gold sensing electrode was not available for pulp potential surveys performed at Kidd Creek. These were performed with a platinum sensing electrode.

3.2 Galvanic Interactions

In order to create a workable theory of flotation it is necessary to understand the interaction of minerals with each other, grinding media and reagents present in the system. Single mineral studies abound (Richardson et al., 1984; Roos et al., 1990; Sun et al., 1992; Woods et al., 1990) and have shown significant correlation between flotation response and pulp potential. However, it is necessary to consider that results of these studies cannot, in most cases, be extrapolated successfully to mixed systems.

In general, the rates of reaction are increased when galvanic coupling exists. Majima (1969) discovered that galena experienced increased oxidation rates in the presence of pyrite. Also, while studies have indicated that pure chalcopyrite samples floated strongly without collector (Heyes et al., 1977), chalcopyrite in the presence of other sulphide minerals had its natural floatability severely reduced (Grano et al., 1990).

Hayes and Ralston (1988) have discovered that grinding galena and chalcopyrite together in oxidising conditions (in a ceramic mill) led to a decrease in flotation recovery and selectivity. This could be due to continued dissolution of metal ions with redeposition of surface species indiscriminantly across the minerals. These same minerals ground in reducing environments (cast iron mill) could be selectively separated collectorlessly using pulp potential control. The lack of oxygen in a cast iron mill will retard surface species formation as electron transfer is hindered. Galvanic interaction can therefore have a beneficial or deleterious effect on flotation response depending on the amount of oxidation/reduction which is optimal for a particular mineral flotation.

3.3 Surface Product Formation and Ep

While the prediction of adsorption of thiol collectors is one use of electrochemical measurements, the creation of specific surface products is another. Small changes in the mineral surface or the production of surface products can change the flotation response dramatically (Finkelstein et al., 1975).

As stated by Hayes and Ralston (1988):

> *"We stress that it is the exact state of the surface of the sulphide particle at the moment of its capture by a gas bubble that must be determined if an unequivocal correlation with flotation response is to be obtained"* (p.77)

The importance of identification and quantification of surface products and the resulting impact on flotation is revealed in the large amount of research dedicated to this end; including galvanic, electrochemical, adsorption and ion transfer studies.

As an example of the dynamic nature of the surface, the following schematic (presented by Hayes and Ralston, 1988) presents the probable evolution of surface species on galena during collectorless flotation (see Figure 4).

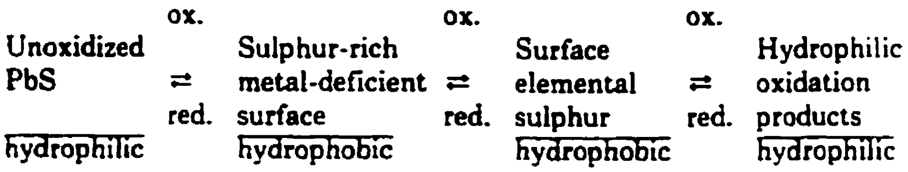

Figure 4. Schematic of the Evolution of Surface Products on Galena During Collectorless Flotation

(from Hayes and Ralston, 1988)

There is continued dispute over the species responsible for collectorless flotation, be it a sulphur rich, metal deficient surface or elemental sulphur. It is possible that these different species represent solely the amount of time allowed for oxidation prior to withdrawing the sample. As seen from the schematic an excess of oxidation can lead to hydrophilic oxidation products which obviously are a detriment to flotation performance.

It is well-documented that for a given pH, there exists a potential range of optimum flotation response, characteristic of each mineral. Hayes and Ralston(1988) found that while chalcopyrite is weakly floatable in reducing conditions, it is strongly floatable at Eh ranges of 0-100 mV (SHE). Also, this condition is reversible when the potential is cycled. Only very extended periods of oxidation can lead to a decrease in flotation response. Galena, however, rapidly oxidises and floats readily at

550 mV (SHE). Beyond this point (assumed to be the point when elemental sulphur is formed) flotation drops off dramatically. Strongly reducing conditions will restore floatability. However, if the mineral is over-oxidised, the condition is irreversible and it is unfloatable at all Eh ranges. Sphalerite is difficult to oxidise, but once this state is achieved, sphalerite floats strongly and independently of Eh.

The above observations were made on single minerals, in collectorless systems. The interactions of these minerals with each other and grinding media (galvanic effects) also has a pronounced impact on selectivity and floatability. These effects are also not predictable based solely on single mineral studies.

3.4 The Role of Oxygen

The degree of oxidation of mineral slurries has long been known to affect flotation performance. Extensive oxidation may cause difficulties in flotation with typical sulphide collectors, but even if the extent of oxidation is not detectable by usual analysis, it may have a significant effect on flotation.

Many sulphides at very low levels of oxidation are naturally floatable without collectors; oxidation only slightly beyond this point destroys this floatability, but then appears to be the condition for optimum floatability with collector. Further oxidation increases collector requirements and slows flotation. (Mineral Processing Handbook, Chap.8)

Gaudin (1957) has stated that thiol collector adsorption cannot be achieved without oxygen, while others have shown that xanthate adsorption can be hindered by adsorbed oxygen coverage of the mineral surface (Poling et al., 1963). Therefore, the role of oxygen in the adsorption of thiol collectors and the production of a "suitable" mineral surface is one that continues to demand investigation.

Fuerstenau et al. (1990) investigated the mechanisms of thiol adsorption with and without oxygen in the system. It was concluded that when oxygen was excluded from the slurry, a previously adsorbed surface species would have to be replaced in order for chemisorption of the xanthate ion to occur. The substituted surface species is suggested to be the hydroxyl ion. It was discovered in this research, as well as by Gaudin (1957), that a ten-fold increase in hydroxyl ion concentration (a pH increase of one) required an order of magnitude increase of xanthate concentration for constant adsorption density (see Figure 5).

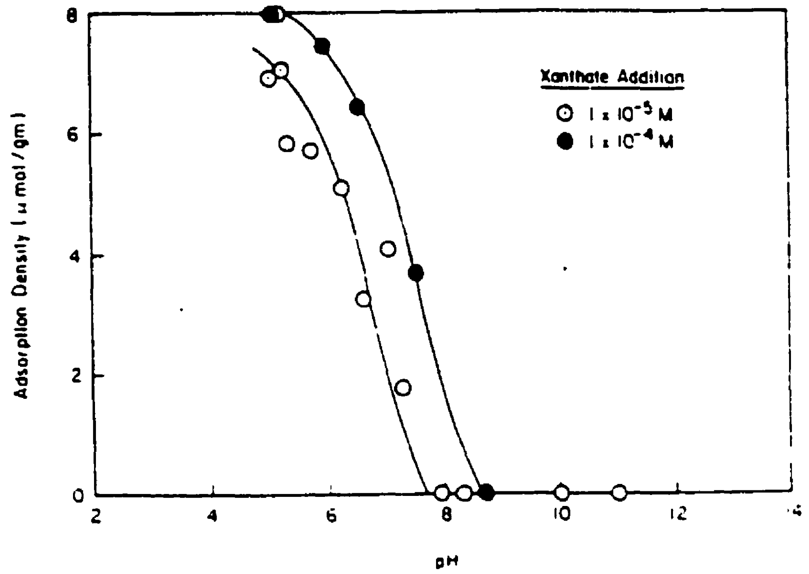

Figure 5. Adsorption Density of Xanthate as a Function of pH in the Absence of Oxygen

(from Fuerstenau, Natalie and Roe, p. 94)

Oxygen in a complex sulphide system (and specifically involving pyrite) has several roles (Martin et al., 1989). Firstly, the galvanic coupling of minerals is increased (see Figure 6) as oxygen acts as an electron acceptor reducing to hydroxyl ions. The creation of hydroxyl ions at the surface is then the second effect of oxygen. While pyrite recovery increased when nitrogen was used as a flotation gas, this was only the case if xanthate was added after enough oxygen had entered the system to create a pulp potential high enough for dixanthogen formation. If conditions were not created which were suitable for dixanthogen formation at the pyrite surface, its flotation was severely hindered. This suggests then, that the role of nitrogen was to sever the galvanic interaction occurring between pyrite and the other minerals present (pyrite was the most cathodic of the four minerals of the study: pyrite, chalcopyrite, galena and sphalerite). The decreased galvanic activity due to the absence of oxygen hindered the formation of hydroxyl ions and therefore the hydrophilic layer on the surface of pyrite.

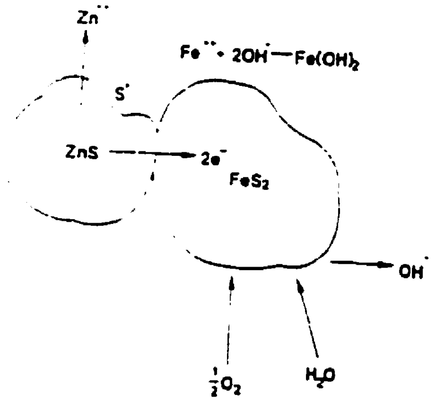

Figure 6. Galvanic Coupling of Minerals

(from Martin, Rao and Finch, p.106)

As previously mentioned in section 2.1.3, dixanthogen need not be the only reaction product at the surface of the mineral. While oxygen might act as an electron acceptor for the dixanthogen reaction, it might also serve to "loosen" the outer layer of the mineral's surface by reacting with sulphide or hydrosulphide ions (Poling, 1976). The oxidation reaction would expose the outer cations and enable the formation of metal-thiolates. This same oxidation reaction could also reduce the hydration of the surface, and make collector adsorption easier (Plaksin et al., 1957).

Determination of the rate of oxidation of minerals is of importance when trying to uncover the effect this oxidation has on flotation performance. This rate has been found to depend on several variables (Ralston, 1991): surface area available for reaction; the partial pressure of oxygen; the type and composition of the mineral; pH and temperature. The difficulty in maintaining these variables constant has made measuring the extent of mineral particle oxidation a complex task.

Accurate measurement of dissolved oxygen content in mill slurries can often be prohibitively difficult. Fresh sulphide surfaces consume oxygen rapidly and removal of samples from the process stream often results in low estimates of the actual dissolved oxygen content. Unfortunately, in high flow streams, a stable reading in-situ is often impossible as entrained air can cause large fluctuations in the readings.

In a bulk system, the extent of oxidation can be measured by using oxygen demand (Spira and Rosenblum., 1974) or, as introduced here, the "Dynamic Dissolved Oxygen" (DDO). It has been shown by Spira and Rosenblum that oxygen demand can be used as an indicator of the extent of oxidation.

The rate of change measured by a dissolved oxygen probe in a laboratory flotation cell can be influenced by several factors such as impeller speed and the surface area of the cell. Only by isolating the amount of oxygen actually consumed by the pulp (by subtracting the amount of oxygen diffusing out of the slurry and adding the amount entrained) could the true DDO be calculated. However, if the flotation machine, flowrates and cell dimensions are kept constant, the only change in rate should be due to the changes in the oxygen demand.

4.0 Method of Attack

4.1 Lab Scale Flotation Tests

In order to obtain the pulp potential "window" of selectivity, the pulp potential must be modified by either chemical or electrical means. As discussed, oxygen and nitrogen were chosen for this purpose due to their applicability to the plant environment.

It was decided to concentrate on methods of ascertaining the degree of oxidation and its effect on the mineral surface and flotation response. The extent of oxidation was monitored through the use of oxygen demand, the EDTA extraction technique and pulp potential.

A schematic of the flotation procedure is presented in Figure 7. The flowsheet was modelled after the Kidd Creek procedure.

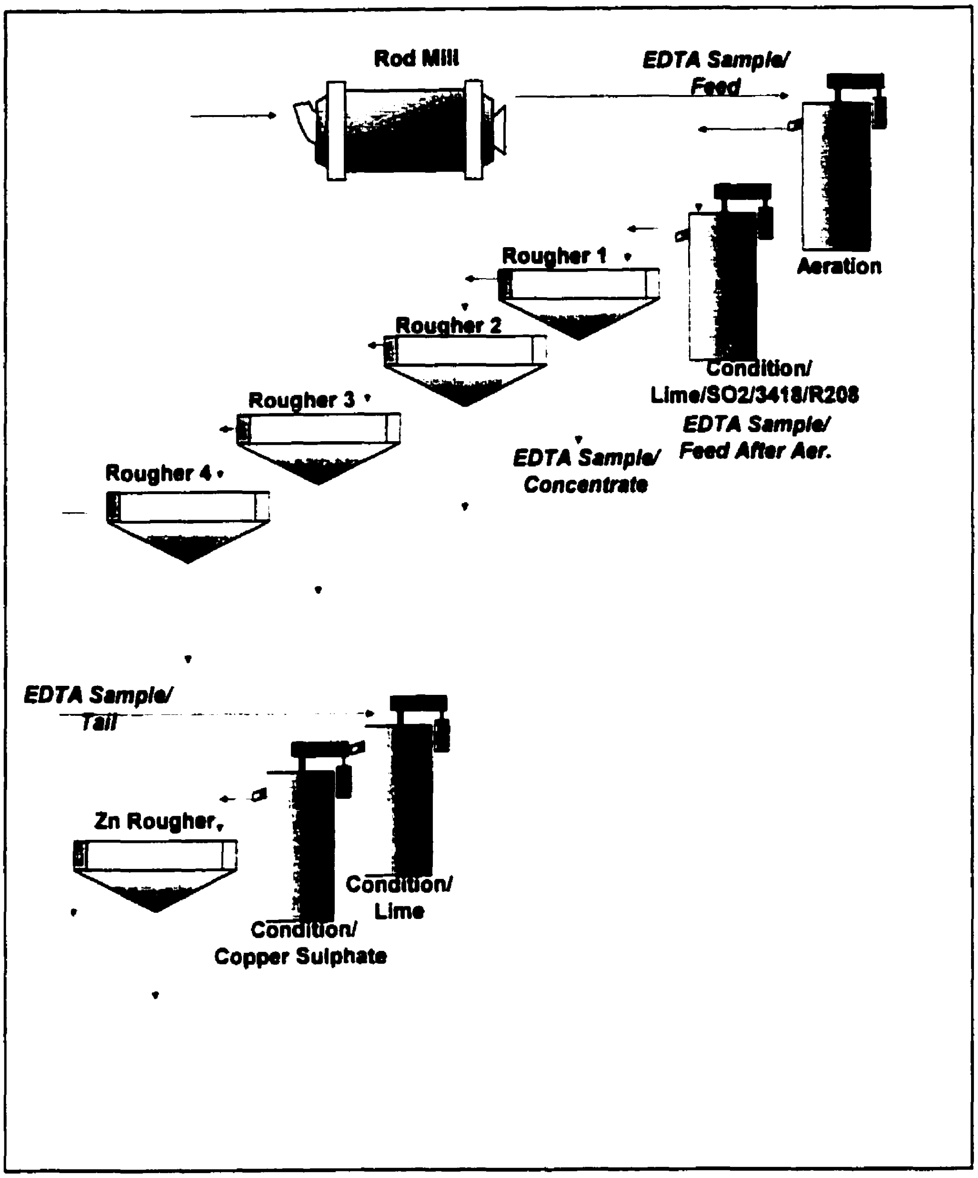

Figure 7. Lab Scale Flotation Flowsheet

Approximately 100 kg of rod mill feed was received from Kidd Creek. This was crushed to -8 mesh (Tyler) and split into charges of 1 kg. A standard grind to 50% -45µm (325 mesh Tyler) was performed in a mild steel rod mill. The pulp was discharged into a lab-scale Agitair flotation cell equipped with a data acquisition system (see Figures 8-10). The data acquisition system (DAS) was built to allow for automatic recording of pulp potential, dissolved oxygen and pH. The DAS was calibrated daily and checked before each test.

A sample was taken for EDTA extraction. The pulp was aerated and reagents added as necessary. Another sample was taken for EDTA extraction. Flotation was performed in stages of 30sec, 30sec, 1 minute and 2 minutes. Samples of the concentrate from the first thirty seconds and of copper circuit tail were taken for EDTA extraction. The pH was increased to 11.5 and 415 g/t of copper sulphate was added. A thirty second zinc flotation stage was performed. An equipment and reagent list is presented in Table 1.

Flotation concentrates and tails were air-dried. The residues were then weighed and sent to Kidd Creek for x-ray fluorescence analysis.

Table 1. Equipment and Reagent List

Time and Location of Tests	Measurement	Equipment Used or Reagent Type
Plant Surveys Kidd Creek, 1991	Ep	Sensing - Gold Foil (Cole-Parmer) Reference - Internal Ag/AgCl
	pH	Glass Bulb
	Temperature	Thermocouple
	meter	Orion Research Model SA230 Multimeter
Laboratory Batch Tests (McGill, 1991-1992)	Ep	Sensing - Gold Foil (Cole-Parmer) Reference - Internal Ag/AgCl
	pH	Glass Bulb
	Temperature	Thermocouple
	D.O.	Orion Model 08-99
	Data Acquisition System	A/D Interface Board - DAS-8PGA (Omega) PC Model XT Hanna pH Transmitter HI8614
	SO2	Liquid Gas/Saturated Water
	Lime	97% $Ca(OH)_2$
	Aerophine 3418A	Cyanamid - pure
	R-208	Cyanamid - 1% Solution
	EDTA	Ethyl Diamine Tetraacetic Acid 10% solution heated to 50°C with stochiometric amount of NaOH (2 mol NaOH per mol EDTA)

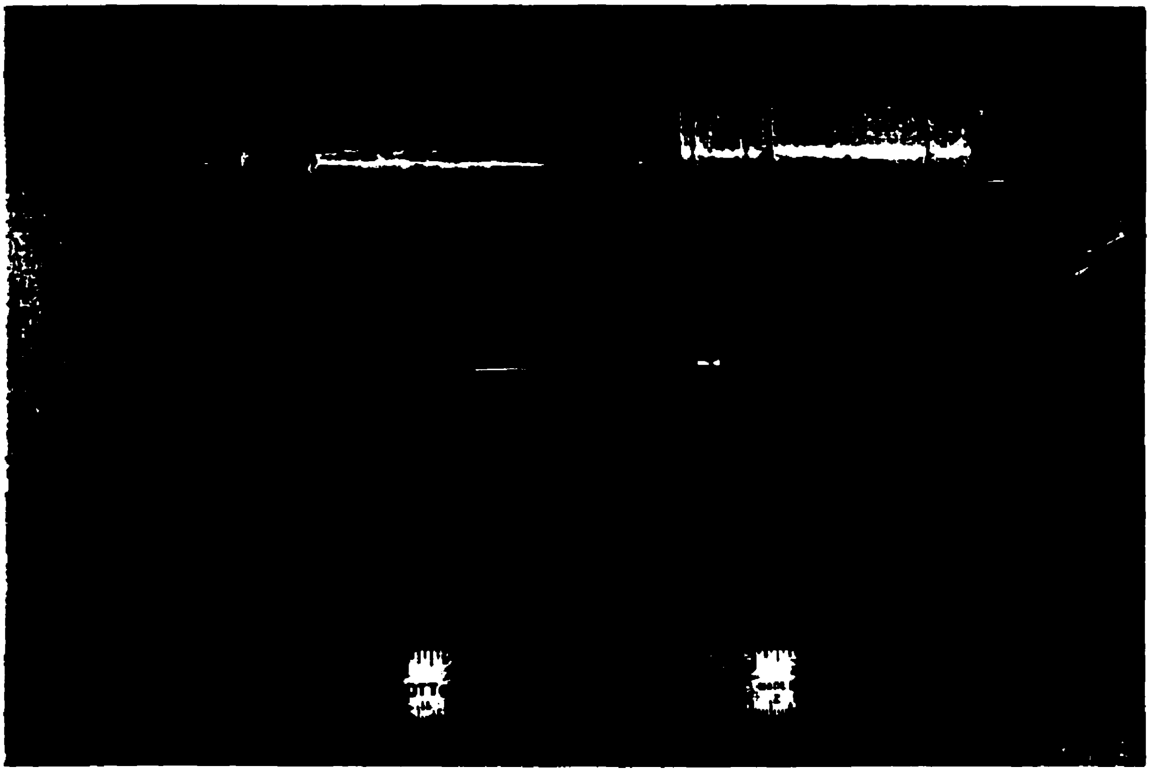

Figure 10. Ep. pH and Dissolved O2 Probes

4.2 Historical Data (Kidd Creek)

The Kidd Creek division of Falconbridge Ltd. operates one industrial, on-line pulp potential probe (gold foil, Ag/ AgCl reference). It is situated in the first cell of the primary rougher bank. Pulp potential data is collected every twenty minutes and stored in a databank allowing for access of up to three months of data.

Pulp potential data was downloaded along with final recoveries, final grades and pH. Monthly, weekly, daily and hourly averages were calculated to see if correlations could be found between final recovery in the copper circuit and the pulp potential measured at the head of the circuit.

Plant surveys with a portable sensor were conducted on B division of the copper circuit over a one month period. Pulp potential, pH and temperature were recorded for each sample point. The pulp potential probe was a lab model Cole Parmer, combination probe. The reference electrode was Ag/ AgCl, while the sensing electrode was a platinum disk (a gold sensing probe was not available). Samples were not withdrawn from the streams since this would distort the readings for the reasons discussed previously. Rather, it was attempted (as far as possible) to completely submerge the electrodes and wait for a stable reading. In flotation this was done at the head of each stage and stability was almost instantaneous. In conditioners and hydrocyclone streams, a stable reading was assumed when readings fluctuated less than ±10 mV.

Also performed were mill surveys using the EDTA extraction technique. Values of pH and Ep were also recorded to ascertain whether extractions were similar in plant operations to those obtained in the laboratory.

4.3 Surface Extraction Techniques

EDTA was chosen as a surface extractant due to its strong complexing abilities with hydroxides, but lack of reaction with sulphides.

A schematic of the procedure is shown in Figure 11.

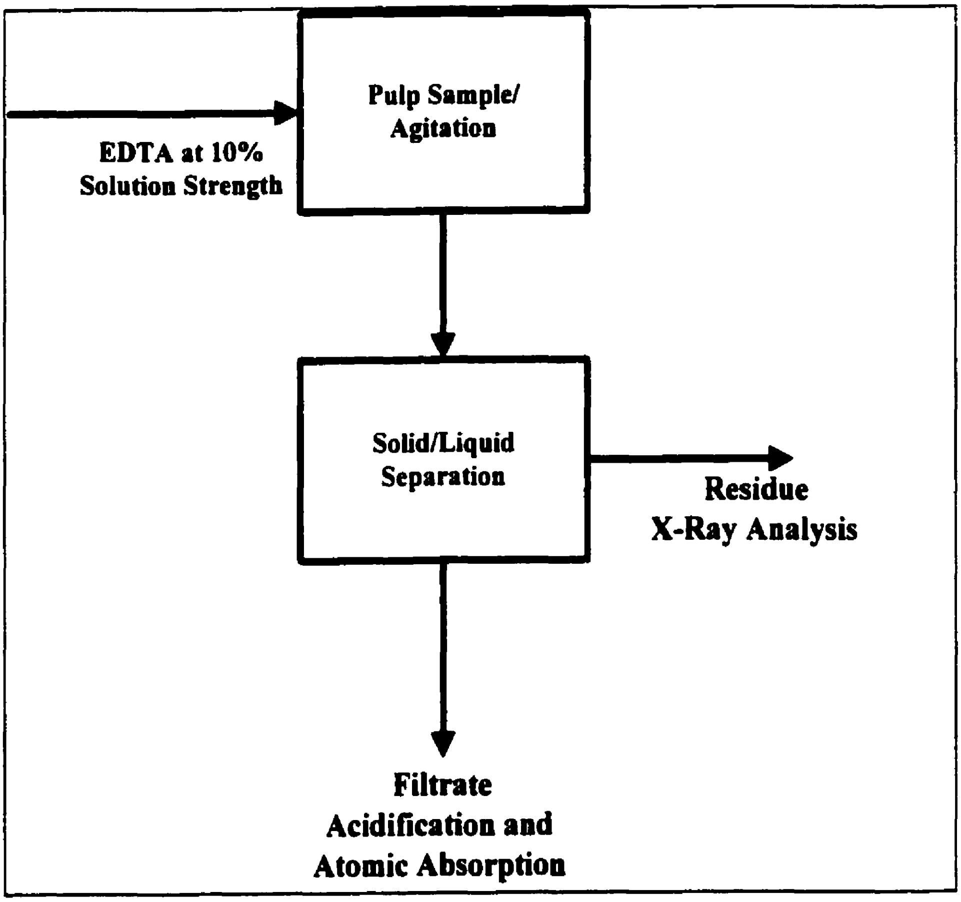

Figure 11. EDTA Extraction Schematic

Pulp samples were withdrawn and EDTA solution immediately added to the pulp (minimum 16g EDTA/kg solid). No significant metal ion concentration was found in solutions from untreated samples. Therefore, any metal ion content present after EDTA addition was assumed to be from loosely-bonded surface species. It was considered imperative to add the EDTA to the slurry sample as quickly as possible to avoid continued evolution of surface products. In order to prepare a solution of EDTA, NaOH and EDTA were mixed at a ratio of 2 moles to 1. A 10% (by weight) EDTA solution was made with distilled water, and the solution was heated to 50°C until dissolution.

These mixtures were shaken for one minute and allowed to stand for thirty minutes. They were then filtered. The solids were dried and sent to Kidd Creek for x-ray analysis of Cu, Zn, Pb, and Fe. The filtrates were analysed for the same elements by atomic absorption at McGill University.

An attempt was made to correlate this data to pulp potential, oxygen demand and metal cation recovery.

4.4 Calibration of Probes

The calibration of pH probes is straightforward as standards exist for comparison. They are readily available and affordable. The same is not true for pulp potential probes. These probes cannot be "calibrated" only tested to determine their accuracy in standard solutions. Faulty readings could lie with either side of the couple(reference/sensing) and some lengthy investigative comparisons can ensue.

The standard practice for checking these probes is either to use quinhydrone or ferrous/ferric solutions, and check versus accepted potential values for these solutions (ASTM standards, 1986; Natarajan et al., 1973).

4.4.1 Laboratory Flotation Tests

All probes were calibrated daily, and re-checked before each flotation test. Pulp potential probes were checked against saturated quinhydrone solutions in buffers of pH 4 and 7 as recommended by the manufacturer. pH probes were calibrated in buffers 4,7, and 10. The oxygen probe was calibrated at its internal zero calibration and in oxygen saturated water.

4.4.2 Mill Surveys

All probes were checked daily before each mill survey. Pulp potential probes were checked against a Fe(II)/Fe(III) solution, while pH probes were checked against buffers 4, 7, and 10.

4.5 Measurement of Dynamic Dissolved Oxygen

For the purpose of this study the DDO has been defined as the maximum rate of change of dissolved oxygen in the slurry when aeration has been interrupted. DDO can then be used to gauge the oxygen demand of the system or the degree to which oxidation has progressed. (see Figure 12)

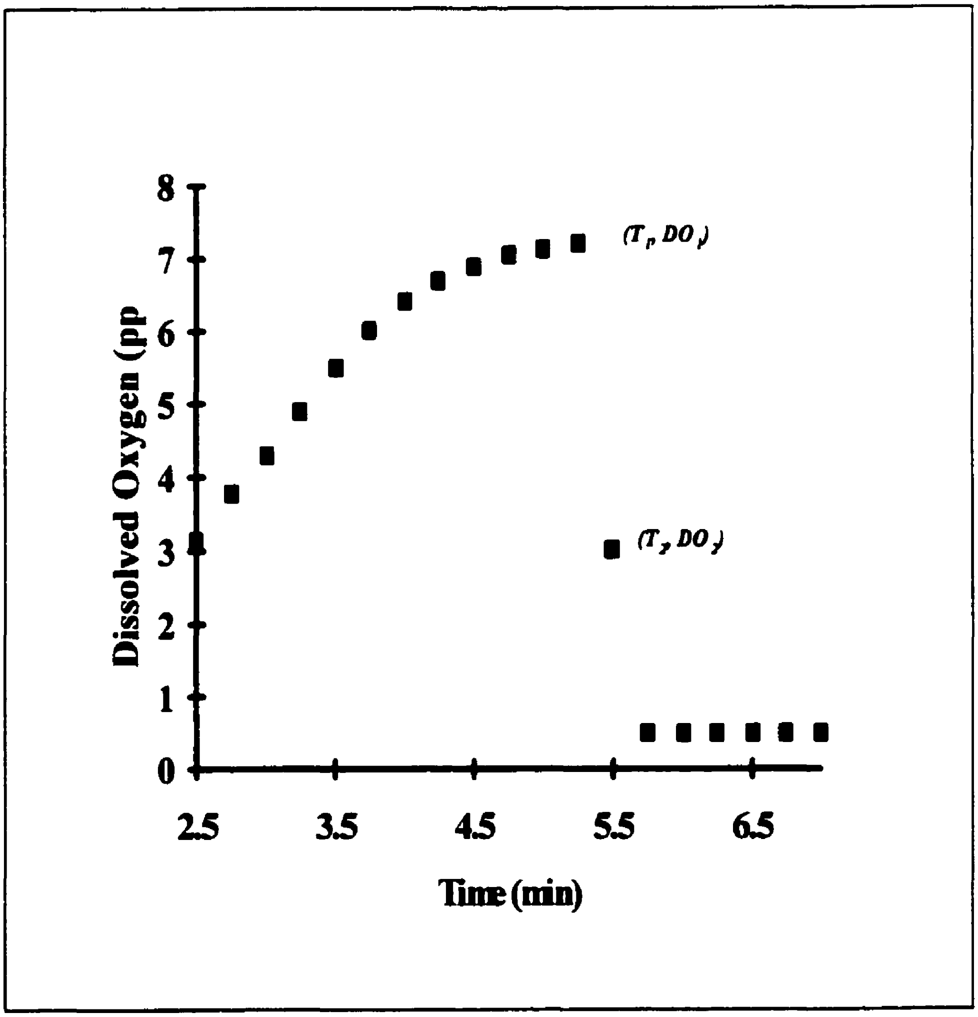

Figure 12. Example of Dissolved Oxygen Response to Aeration which is Shut-off at ~5.2 min.

NOTE: $DDO = (DO_2 - DO_1)/(T_2 - T_1)$

Spira and Rosenblum (1974) used a one minute interruption of aeration time, during which the dissolved oxygen was measured. This method must be used with some caution, because dissolved oxygen levels of zero could be reached in that one minute period and therefore the rates measured would be distorted (see Figure 13).

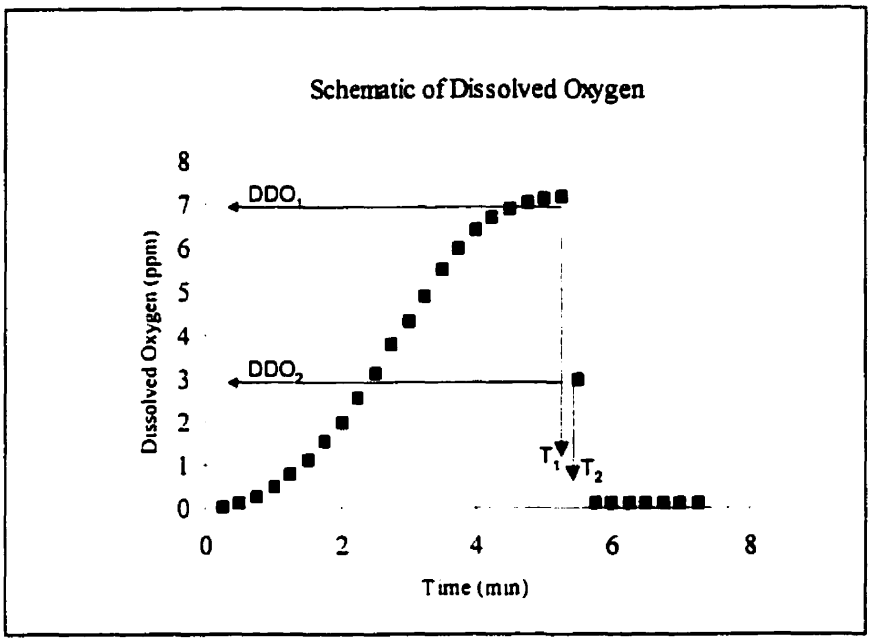

Figure 13. DDO (0 ppm reached in less than 1 minute).

An attempt was made in this study to use the maximum rate of change occurring at the beginning of the interruption of aeration. Reagent addition and flotation performance were then compared to DDO in the hopes of discovering a correlation.

5.0 Raw Data

5.1 Lab Flotation Tests - McGill

Presented in Table 2 are the conditions for the batch tests performed at McGill University. All flotation condition sheets are presented in the appendix (Testwork Details) along with complete metallurgical results. Repeats were made of the air, no reagent flotation case to check reproducibility. Results are presented in the Appendix. Presented in Table 3 is the terminology of the parameters used to examine the results and Table 4- Table 6 contain a summary of the generated data.

Table 2. Test Variables and Reagent Conditions

Variable	Level or Type
Conditioning Gas	Air, Nitrogen
Flotation Gas	Air, Nitrogen
Ep Levels (mV)	-220, -150, -100, -50, -25, 0, 25
Lime (g/t)	100
Sulphur Dioxide (g/t)	450
3418 - Cytec (g/t)	25
R-208 - Cytec (g/t)	10

The following Reagent Combinations were tested:

(i) No Reagent
(ii) SO2 at Specified Ep
(iii) SO2 + Lime at Specified Ep
(iv) SO2 + Lime + Collector at Specified Ep

Table 3. Terminology

Character	Name	Units
E_p	Pulp Potential	mV vs Ag/AgCl (reference)
E_h	Standard Electrochemical Potential	mV vs Standard Hydrogen Electrode
E_m	Extractive Grade	mg metal extracted per gram sample
E_s	Extractive Recovery	mg metal extracted per gram metal in sample
DDO	Dynamic Dissolved Oxygen	ppm O_2/minute
Subscripts		
(fdaer-fd)	feed after aeration and reagent addition - feed	
(t-c)	tails - concentrate	

The effect of the reagent scheme on the following variables was examined:

(a) E_p vs Recovery

(b) E_p vs Cu/Zn and Cu/Fe Selectivity

(c) E_p vs $E_{m(feed)}$

(d) E_p vs $E_{m(t\text{-}c)}$

(e) E_p vs $E_{m(fd\text{-}fdaer)}$

(f) E_p vs E_s

(g) E_p vs Total E_m

(h) E_p vs DDO

Table 4. Pulp Potential, Grades and Recoveries

Reagent Scheme	Test No.	Ep(mV) Ag/AgCl	Grade, %				Recovery %				Zn Col, %Zn	
			Cu	Zn	Pb	Fe	Cu	Zn	Pb	Fe	Grade	Rec.
No Reagents Nitrogen Flot.	11	-230	2.08	7.35	1.07	21.6	7.66	13.10	64.80	13.90	21.4	41.6
	12	-100	8.82	8.62	0.64	24.60	46.50	21.00	63.89	23.03	24.2	58.4
	15	-50	8.31	8.67	0.66	24.27	48.32	23.76	68.67	24.49	28.8	49.5
No Reagents Air Flot.	16	-230	6.95	9.76	0.72	22.47	42.43	26.88	70.92	23.19	31	51.1
	20	-150	7.65	9.32	0.42	22.04	59.67	29.51	56.61	27.86	30.1	45.8
	18	-100	9.25	12.32	0.50	24.01	69.70	42.95	68.97	32.04	27.3	42.9
	13	-50	11.34	11.89	0.51	25.64	71.15	35.22	64.98	28.37	30.4	46.7
	19	-25	8.58	10.17	0.50	22.15	63.60	33.53	62.23	28.99	28.4	48.6
	21	0	7.81	9.93	0.46	21.66	60.71	32.82	61.35	29.76	28	45.8
	17	25	10.79	13.48	0.47	25.27	74.80	44.71	69.13	31.60	24.3	39.6
SO2 Addition Nitrogen Flot.	44	-230	3.58	6.46	0.41	18.54	23.82	20.32	50.64	21.22	23	35
	48	-150	5.23	6.33	0.35	19.43	28.99	16.08	44.24	18.78	25.4	38.2
	46	-100	5.82	6.60	0.37	19.48	34.86	18.22	47.52	19.68	31.1	41.5
	45	-25	6.84	6.92	0.39	19.69	47.42	21.08	53.81	22.53	29.8	53
	49	0	6.87	6.85	0.32	19.42	47.44	20.78	45.35	21.55	34.1	44.6
	47	25	7.73	7.56	0.31	19.55	56.06	23.24	46.17	22.61	34	49
SO2 Addition Air Flotation	26	-230	5.88	7.66	0.52	20.14	39.68	21.62	51.77	23.48	34.1	49.5
	27	-150	6.49	7.78	0.41	20.70	50.16	24.76	54.42	27.86	35.9	54
	24	-100	6.95	7.38	0.41	20.19	52.36	23.58	52.22	25.97	33.4	53.3
	28	-50	7.34	8.24	0.38	20.46	56.51	27.61	54.43	28.43	30.5	52.7
	25	0	8.55	8.47	0.44	22.03	63.39	26.86	55.49	29.20	38.2	50.7
	29	25	9.11	9.67	0.46	22.11	61.51	28.05	54.54	26.75	26.4	57.3

Reagent Scheme	Test No.	Ep(mV) Ag/AgCl	Grade, %				Recovery %				Zn Col,%Zn	
			Cu	Zn	Pb	Fe	Cu	Zn	Pb	Fe	Grade	Rec.
SO2+Lime	51	-230	2.08	5.64	0.48	17.88	8.98	11.92	44.40	13.80	16.5	35.4
Nitrogen Flot.	52	-100	5.43	5.97	0.43	19.17	28.28	14.34	45.23	17.78	29.2	42.1
	53	-25	7.85	8.16	0.31	19.26	59.91	25.51	51.23	24.43	29.9	52.3
	54	25	7.40	8.23	0.32	19.03	63.82	28.47	52.46	25.68	24.7	58.8
SO2+Lime	30	-230	5.57	6.79	0.58	20.53	29.14	15.63	49.97	19.25	24.5	62.9
Air Flot.	33	-150	7.07	7.68	0.44	21.57	47.41	22.09	51.50	26.35	29.2	59.2
	35	-100	7.63	7.75	0.41	21.69	51.05	22.27	50.17	25.66	34.2	52.4
	34	-25	8.37	7.98	0.44	21.73	60.91	24.85	55.48	28.24	32.5	58.1
	36	0	9.19	9.61	0.45	21.86	53.74	24.32	49.52	23.34	27.6	59.1
	32	25	8.92	9.56	0.46	22.03	56.64	24.83	51.44	24.83	26.6	60.1
Full Reagents	59	-150	6.94	5.77	0.45	22.89	75.82	29.81	85.79	39.66	35	32.9
Nitrogen Flot.	57	-100	7.83	5.99	0.41	24.17	79.40	28.35	85.44	43.60	37.5	43
	60	-50	7.67	7.73	0.39	22.55	74.65	34.30	85.18	41.58	39	25.8
	56	-25	7.14	10.18	0.32	21.87	86.37	55.47	84.66	47.20	36.6	32.1
	61	0	7.22	9.53	0.34	22.40	86.48	51.04	85.70	47.18	39.6	32
	58	25	7.34	10.84	0.34	22.11	87.27	56.72	85.58	48.63	36.6	31.8
Full Reagents	39	-230	8.55	8.08	0.45	26.69	80.86	39.09	79.87	47.25	37.5	48.5
Air Flot.	37	-150	9.02	10.20	0.49	25.89	88.40	48.30	84.44	50.18	44.9	33.9
	41	-100	8.90	10.89	0.45	24.82	87.72	51.56	79.63	48.31	42.8	30.9
	43	-50	7.61	11.43	0.38	22.36	87.15	59.19	72.00	43.69	39.2	27.5
	38	-25	8.22	11.82	0.41	24.11	86.60	53.85	82.52	49.64	38.5	27.8
	40	0	8.63	12.68	0.43	24.92	88.37	60.70	82.10	49.06	33.5	27.7
	42	25	6.88	9.99	0.35	23.25	89.12	59.12	54.11	52.58	41.7	27.7

Table 5. Pulp Potential, DDO, Em and Es

Reagent Scheme	Test No.	Ep(mV) Ag/AgCl	DDO ppm/min	Em(feed), mg ext. per gram solid				Es(feed), mg ext. per gr. metal solid		
				Zn	Pb	Fe	Total	Zn	Pb	Fe
No Reagents	11	-230	-	0.26	0.11	0.83	1.19	4.95	96.94	5.48
Nitrogen Flot.	12	-100	-	0.33	0.18	1.09	1.61	6.51	166.36	7.19
	15	-50	-	0.43	0.17	1.86	2.46	8.38	155.74	12.17
No Reagents	16	-230	1.05	0.46	0.17	1.69	2.32	8.94	157.15	11.97
Air Flot.	20	-150	5.37	0.42	0.19	1.68	2.28	8.83	172.74	14.52
	18	-100	10.68	1.69	0.62	5.94	8.25	7.32	137.08	9.11
	13	-50	5.42	0.40	0.15	1.69	2.24	7.64	145.98	10.93
	19	-25	7.99	0.39	0.15	1.61	2.15	8.02	146.18	13.57
	21	0	6.63	0.34	0.13	1.34	1.80	7.11	121.68	11.58
	17	25		0.36	0.15	1.25	1.75	6.98	142.71	9.06
SO2 Addition	44	-230	0.00	0.39	0.19	1.68	2.27	9.19	196.76	12.86
Nitrogen Flot.	48	-150	5.07	0.40	0.25	1.68	2.34	8.83	240.20	12.50
	46	-100	6.09	0.26	0.18	1.15	1.60	5.68	208.68	8.83
	45	-25	-	0.37	0.19	1.61	2.17	8.14	188.64	12.36
	49	0	10.21	0.39	0.26	1.52	2.16	8.55	247.05	11.06
	47	25	6.09	0.38	0.22	1.50	2.10	8.33	217.46	11.23
SO2 Addition	26	-230	0.00	0.39	0.15	1.60	2.13	8.14	129.97	14.30
Air Flotation	27	-150	2.42	0.38	0.12	1.52	2.02	8.65	126.24	12.72
	24	-100	3.66	0.36	0.13	1.62	2.11	7.51	113.35	13.91
	28	-50	6.54	0.39	0.14	1.70	2.23	8.76	143.79	14.84
	25	0	6.22	0.31	0.12	1.42	1.85	6.89	128.95	12.02
	29	25	3.51	0.38	0.15	1.12	1.65	7.69	146.56	8.92

Reagent Scheme	Test No.	Ep(mV) Ag/AgCl	DDO ppm/min	Em(feed), mg ext. per gram solid				Es(feed), mg ext. per gr. metal solid		
				Zn	Pb	Fe	Total	Zn	Pb	Fe
SO2+Lime Nitrogen Flot.	51	-230	0.00	0.42	0.25	1.62	2.29	9.37	243.40	11.84
	52	-100	9.98	0.36	0.22	1.53	2.11	7.50	198.54	10.96
	53	-25	4.81	0.37	0.23	1.30	1.90	7.64	231.03	8.81
	54	25	3.77	0.38	0.26	1.21	1.85	249.93	8.79	1.85
SO2+Lime Air Flot.	30	-230	0.00	0.35	0.11	1.28	1.74	7.21	99.67	11.22
	33	-150	-	0.42	0.15	1.53	2.11	8.33	130.31	12.73
	35	-100	16.09	0.37	0.13	1.50	2.00	7.27	111.96	12.58
	34	-25	9.06	0.35	0.15	1.50	2.00	6.93	136.88	12.47
	36	0	4.65	0.37	0.14	1.16	1.66	7.45	131.06	9.44
	32	25	5.11	0.39	0.12	1.19	1.70	7.24	98.21	10.17
Full Reagents Nitrogen Flot.	59	-150	-	0.39	0.18	1.61	2.17	8.52	158.48	11.20
	57	-100	5.76	0.38	0.20	1.60	2.18	7.73	191.17	10.61
	60	-50	8.05	0.38	0.17	1.66	2.21	8.36	151.92	11.86
	56	-25	5.80	0.35	0.22	0.37	0.94	7.28	215.07	2.56
	61	0	5.18	0.43	0.18	1.56	2.18	8.31	169.82	10.92
	58	25	5.60	0.39	0.18	1.43	2.00	8.21	177.66	10.23
Full Reagents Air Flot.	39	-230	0.00	0.38	0.11	1.44	1.93	7.32	93.98	12.95
	37	-150	5.66	0.40	0.16	1.68	2.23	6.47	108.73	11.53
	41	-100	6.37	0.40	0.18	0.17	0.76	8.98	208.42	14.41
	43	-50	6.09	0.36	0.21	1.42	1.99	7.37	196.34	9.64
	38	-25	6.17	0.38	0.14	1.58	2.10	7.95	155.00	13.43
	40	0	5.25	0.33	0.17	1.30	1.80	7.19	161.16	11.03
	42	25	6.84	0.35	0.18	1.61	2.14	7.73	167.58	11.80

Table 6. Pulp Potential, Em (fdaer-fd) , and Em (t-c)

Reagent Scheme	Test No.	Ep(mV) Ag/AgCl	Em (fdaer-fd)			Em(Tail-Conc)		
			Pb	Zn	Fe	Pb	Zn	Fe
No Reagents	11	-230	-	-	-	-0.157	-0.268	-0.939
Nitrogen Flot.	12	-100	-	-	-	0.055	0.142	0.29
	15	-50	-	-	-	-0.04	0.036	0.636
No Reagents	16	-230	-	-	-	-0.205	-0.434	-1.91
Air Flot.	20	-150	0.012	0.003	0.029	-0.155	-0.132	-0.104
	18	-100	-	-	-	0.404	1.636	6.68
	13	-50	-	-	-	-0.187	-0.048	0.06
	19	-25	0.001	-0.044	-0.133	-0.086	-0.024	0.319
	21	0	-	-	-	-0.128	-0.027	0.114
	17	25	0.03	0.016	-0.156	-0.008	0.108	0.383
SO2 Addition	44	-230	0.011	-0.008	0.008	-0.15	-0.189	-0.476
Nitrogen Flot.	48	-150	0.007	0.037	0.218	-0.12	-0.117	-0.294
	46	-100	-0.001	-0.138	-0.52	-0.096	-0.127	-0.127
	45	-25	-0.02	-0.046	-0.054	-0.065	-0.028	0.277
	49	0	0.005	-0.005	-0.046	-0.021	-0.002	0.299
	47	25	0.007	-0.063	-0.285	-0.003	0.025	0.443
SO2 Addition	26	-230	0.016	-0.015	0.104	-0.177	-0.364	-0.81
Air Flotation	27	-150	-0.002	-0.003	0.03	-0.069	-0.208	-0.327
	24	-100	0.019	-0.003	0.007	-0.127	-0.253	-0.538
	28	-50	-0.017	-0.03	0.087	-0.046	-0.081	-0.266
	25	0	-0.019	-0.062	-0.229	-0.086	-0.094	-0.08
	29	25	0.001	-0.032	-0.411	0.003	0.09	0.313

Reagent Scheme	Test No.	Ep(mV) Ag/AgCl	Em (fdaer-fd)			Em(Tail-Conc)		
			Pb	Zn	Fe	Pb	Zn	Fe
SO2+Lime Add.	51	-230	0.023	0.01	-0.004	-0.23	-0.267	-0.774
Nitrogen Flot.	52	-100	0.011	-0.048	-0.018	-0.142	-0.163	-0.331
	53	-25	0.03	-0.052	-0.3	-0.071	-0.016	0.16
	54	25	0.016	-0.019	-0.434	-0.079	-0.051	-0.022
SO2+Lime Add.	30	-230	-0.014	-0.025	-0.024	-0.144	-0.4	-1.028
Air Flot.	33	-150	-0.003	0.001	0.097	-0.141	-0.268	-0.569
	35	-100	-0.012	-0.042	-0.024	-0.074	-0.161	-0.33
	34	-25	-0.021	-0.071	-0.139	-0.088	-0.133	-0.361
	36	0	0	-0.017	-0.357	-0.08	-0.07	-0.203
	32	25	0.012	-0.048	-0.371	-0.039	0.052	0.203
Full Reagents	59	-150	-0.028	0.002	0.031	0.084	0.242	1.326
Nitrogen Flot.	57	-100	0.044	-0.021	0.173	0.149	0.254	1.278
	60	-50	-0.024	-0.023	-0.043	0.049	0.229	1.216
	56	-25	-0.007	-0.097	-1.269	0.112	0.205	0.944
	61	0	0.012	-0.013	-0.274	0.101	0.211	1.221
	58	25	-0.028	-0.069	-0.139	0.096	0.248	1.091
Full Reagents	39	-230	0.014	0.076	0.316	0.022	0.106	0.828
Air Flot.	37	-150	0.025	0.074	0.318	0.059	0.193	1.245
	41	-100	0.007	-0.022	-0.004	0.124	0.252	1.389
	43	-50	0.026	-0.038	-0.082	0.092	0.137	0.714
	38	-25	0.031	-0.043	0.009	0.029	0.14	0.86
	40	0	0.006	-0.073	-0.338	0.086	0.236	0.96
	42	25	-0.066	-0.062	-0.035	0.084	0.206	1.082

5.2 Surveys

5.2.1 Downloaded Data - Pulp Potential vs Recovery

Pulp Potential measurements from March to May 1990 were downloaded from the Kidd Creek database in order to examine any correlations which existed between copper recovery and pulp potential. Three months of data are presented in Figures 14-16 and show little correlation between recovery and pulp potential. It is probable that ore and reagent changes mask the effect of pulp potential as mill conditions are in constant flux.

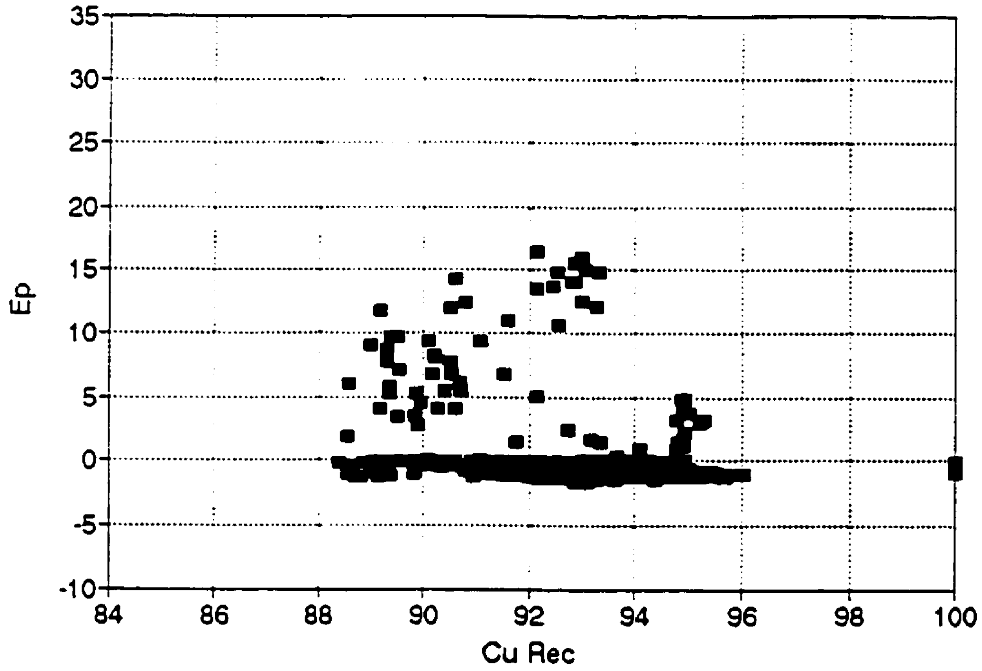

Figure 14 . March Averages

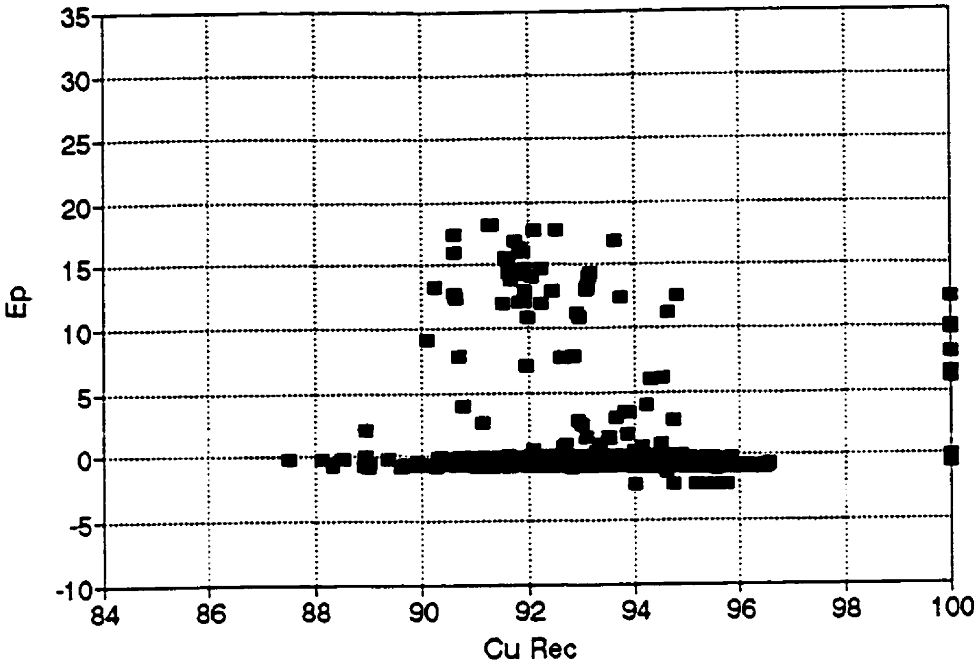

Figure 15. April Averages

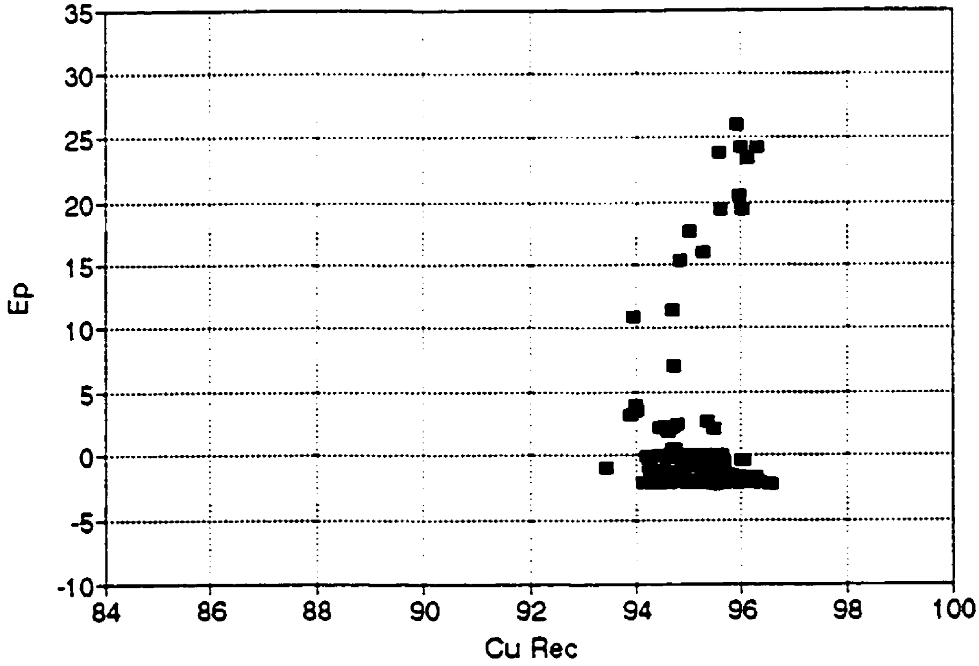

Figure 16. May Averages

5.2.2 Mill Surveys (1990)

The survey data presented in Table 7 provided a baseline of pulp potential and pH values in the Kidd Creek copper flotation streams. As previously mentioned, the only pulp potential values measured at Kidd Creek were the levels in the primary copper rougher flotation bank, and these proved difficult to compare with final copper recoveries as many variables would mask the effect of pulp potential. This set of mill surveys, then , was undertaken in order to check the pulp potential (and corresponding pH levels) in various streams.

5.2.3 EDTA Extraction of Mill Products

A survey was performed in 1992 to compare the extraction with EDTA from mill samples freshly removed from the flotation stream at Kidd Creek and laboratory data generated at McGill University. Results are presented in Table 8, and comparisons appear in section *6.0 Discussion.*

Table 7. Mill Survey Data: Pulp Potential and pH

Date	Time	Primary Ball Mill Discharge		Primary Cyclone O/F		Primary Rougher		3rd Cleaner	
		Eh	pH	Eh	pH	Eh	pH	Eh	pH
7/9/90	10:00 -11:30	100	8.24	157	8.48	185	6.86	276	7.95
7/11/90	13:15 - 14:30	190	8.84	205	9.23	184	7.20	352	8.27
7/12/90	8:20 - 9:35	170	8.60	171	8.92	201	7.15	401	8.15
7/13/90	8:15 - 9:25	160	8.70	184	8.66	200	7.06	413	8.19
7/17/90	9:15 -11:00	144	8.75	188	8.82	307	6.96	375	7.98
7/18/90	8:15 - 9:30	20	8.07	85	8.37	211	7.93	410	8.00
7/23/90	9:35 - 10:35	210	8.00	185	9.00	218	7.00	304	8.00
7/23/90	11:00 -12:00	193	8.36	195	8.74	228	6.89	380	8.08
7/23/90	13:00 - 14:00	108	8.05	188	8.28	211	6.90	280	8.22
7/23/90	14:55 -15:55			182	8.15	248	6.81	306	8.08
7/24/90	8:20 - 9:30	-141	7.80	14	7.90	220	6.58	380	7.88
7/24/90	10:30 - 11:30	-60	8.00	17	7.90	205	6.48	337	7.70
7/25/90	8:00 - 9:00	-10	7.86	109	8.07	210	6.90	307	7.95
7/25/90	9:50 - 10:50	-35	7.65	84	8.07	208	6.53	346	7.92
7/25/90	12:45 - 13:45	-10	7.86	109	8.07	210	6.90	307	7.95
7/25/97	14:00 - 15:00	60	8.03	145	8.25	215	6.98	320	8.00
7/25/90	16:30 - 17:30	20	7.96	139	8.10	218	6.77	312	7.85
7/25/90	18:20 - 19:20	33	8.26	151	8.46	220	6.86	307	7.93
7/25/90	19:10 - 20:10	-1	7.90	110	8.31	204	6.78	314	7.97
7/30/90	8:15 - 9:15	220	8.40	194	9.60	160	6.44	306	7.79

Table 8. EDTA Extraction of Mill Products

		Em(mg ext. metal/gram solid)				Ep(mV)	
Test #	Sample	Cu	Zn	Pb	Fe	Ag/AgCl	pH
Run 1	Cyclone O/F	0.0149	0.1983	0.0423	1.3263	-56	8.3
	Rougher Feed	0.0075	0.1566	0.0284	0.7975	-20	8.1
	Rougher Tail	0.0088	0.2008	0.0395	1.1194	6	8.2
	Scavenger Feed	0.0115	0.2575	0.0893	1.4012	42	7.8
	Scavenger Tail	0.0115	0.2651	0.0890	1.1116	55	7.8
	Cleaner Feed	0.0053	0.2181	0.0816	1.3534	36	8.1
	Cleaner Tail	0.0168	0.2710	0.1099	1.6266	46	8.1
Run 2	Cyclone O/F	0.0021	0.1081	0.0024	0.5431	95	10.3
	Rougher Feed	0.0000	0.1839	0.0122	0.8666	-7	8.3
	Rougher Tail	0.0000	0.1773	0.0163	0.8643	10	8.6
	Scavenger Feed	0.0000	0.2385	0.0495	1.3648	46	7.8
	Scavenger Tail	0.0000	0.2724	0.0416	1.1714	56	7.8
	Cleaner Feed	0.0000	0.1937	0.0351	1.2838	32	8.1
	Cleaner Tail	0.0000	0.2266	0.0518	1.6057	43	8.0
Run 3	Cyclone O/F	0.0000	0.1192	0.0072	0.7384	-99	10.3
	Rougher Feed	0.0000	0.1518	0.0124	0.9616	-20	8.8
	Rougher Tail	0.0000	0.1578	0.0120	0.8757	-8	8.8
	Scavenger Feed	0.0066	0.2894	0.0336	1.6621	26	8.1
	Scavenger Tail	0.0000	0.2600	0.0426	1.4641	36	8.0
	Cleaner Feed	0.0000	0.2171	0.0335	1.6963	19	8.4
	Cleaner Tail	0.0072	0.4809	0.0367	1.9719	31	8.3
Run 3	Cyclone O/F	0.0035	0.1227	0.0005	0.5967	-95	10.3
	Rougher Feed	0.0000	0.1511	0.0005	0.7091	-13	8.9
	Rougher Tail	0.0000	0.2632	0.0077	1.2168	-6	8.9
	Scavenger Feed	0.0164	0.3618	0.0198	1.8458	29	7.8
	Scavenger Tail	0.0106	0.4645	0.0484	2.0006	42	8.2

6.0 Analysis and Discussion

6.1 Copper

Copper was not extracted by EDTA and concentrations before and after extraction were essentially zero. It has been suggested that chalcopyrite releases iron but not copper from the sulphide lattice (Rumball, 1996). Also, it may be possible that copper substitution in the pyrite and/or sphalerite lattice "protects" copper from EDTA extraction. XPS studies conducted by Smart (1991) have also failed to find copper species on the surface of flotation products.

Copper can tend to react with sulphide minerals in the following way(Nicol, 1984):

$$MS + Cu^{2+} \rightarrow CuS + M^{2+}$$

which suggests covellite formation on the surface (other research (Perry, 1984) suggests the surface product is chalcocite). It is unknown to the author whether these secondary copper minerals can be dissolved by EDTA. If they cannot, it may suggest the reason for the lack of Cu extractability.

Whatever the cause, copper could not be examined in this study.

6.2 EDTA Procedure

It has recently been suggested that de-oxygenation of the pulp is necessary to avoid continued oxidation of the mineral surface during the EDTA extraction process (Rumball, 1996). A de-oxygenation process was not performed on the samples analysed in this testwork which may therefore indicate an upward bias of metal extraction. Further study would be needed to ascertain the effect of oxygen contained in the pulp water.

A ½ hour leach time was used and this may have been insufficient for the complete dissolution of the iron (Rumball, 1996). Again, the effect of leach time on extractable species would be an area of further investigation. It may depend on mineral type, oxidation product removed, temperature, pH, EDTA concentration, etc. However, since trends are sought, not absolute quantities, a consistent procedure should still reveal them, and therefore provide practical information.

6.3 Pulp Potential vs Recovery and Separation Efficiency

6.3.1 Introduction

The objective of this set of analyses was the determination of a pulp potential range which corresponded to the highest recoveries of each metal cation examined (copper, lead, zinc, iron). As previously mentioned, a lack of oxygen can inhibit collector adsorption, while over-oxidation of some minerals can lead to poor flotation response. The objective then, is to analyse the data produced searching retrospectively for any relationships that exist. While the determination of the "window" of pulp potential which allows for the greatest copper recovery is of importance, the selectivity between chalcopyrite and other minerals in the copper rougher flotation circuit is also critical. Each addition to the reagent scheme, be it sulphur dioxide, lime or collector, is designed to increase the selectivity of chalcopyrite vs pyrite or sphalerite. The improvement in selectivity can be achieved by either the depression of mineral A versus mineral B, or by increasing the kinetics of flotation of mineral A versus that of mineral B. Shown in Table 4, and Figure 17-Figure 26, are the final recoveries of copper, zinc and iron as well as the selectivities of Cu/Fe and Cu/Zn. Selectivities are stated as the separation efficiency (SE) and are calculated as: %Cu recovery - %Zn (or %Fe) recovery.

Sulphur dioxide and lime act to slow the flotation of sphalerite and pyrite. The reducing action of sulphur dioxide can prevent the activation of pyrite and sphalerite by limiting oxidation (Wills, 1984), while the action of lime has been previously discussed. Selective collectors, used with the proper pulp chemistry, adsorb selectively onto the desired mineral and thereby improve flotation kinetics.

It is impossible to attain 100% selectivity in the rougher stage of flotation even with the "perfect" reagent scheme. One limit is that 100% liberation of minerals is rarely the objective of a primary grind, and a regrinding stage is often used to further liberate the minerals for cleaning. Selectivity in a rougher stage of flotation should be maximised, but not to the detriment of valuable mineral recovery. Bearing this in mind, Cu/Zn and Cu/Fe selectivities in the Kidd Creek copper rougher should be high without prejudicing copper recovery.

6.3.2 Air Flotation

As shown in Figure 17-Figure 19, the addition of SO_2 retarded the flotation of copper, zinc and iron. Copper/zinc SE remained unaffected by the addition of SO_2, while the copper/iron SE decreased by almost 10% (see Figure 20). Copper/zinc selectivity changed little in comparison to the flotation with no reagent addition.

The addition of lime further depressed the kinetics of all the minerals examined (chalcopyrite, pyrite and sphalerite). This was especially notable in the range of -230 mV at which no aeration of the pulp had previously occurred. This is substantiated by the previous work of Fuerstenau (1990). The increase in pH due to the lime may have necessitated an increase in collector when in the absence of oxygen (see 3.4 *The Role of Oxygen*). At -100mV, achieved by aeration, copper recovery was similar to that of the SO_2 reagent scheme. The selectivity of copper against zinc and iron were similar to those attained with SO_2.

As expected, the greatest change in recovery and separation efficiency occurred upon the addition of the collectors, 3418A and R208. Both collectors are selective against pyrite in the pH ranges above 9.0. The complete lack of aeration most likely did not allow for efficient collector adhesion as copper recoveries were low at pulp potential levels below -150mV. The recovery of copper did not vary with pulp potential above a minimum of -150mV, but remained almost constant at 88%. Therefore, not only were recoveries of copper up to 20% higher through the use of collector, but the "window" of applicable pulp potential in order to maximize recovery was widened.

The copper/zinc SE was greatest with no aeration (41.8%). Selectivity of copper against zinc gradually dropped from this point, to a minimum of approximately 28%. Copper / iron SE, on the other hand, was a minimum at -230 mV (33.7%) and increased gradually to ≈43% at -50 mV(see Figure 21). It may be that during the aeration process to attain the required pulp potential level, production of oxidised copper species on chalcopyrite allowed for the transfer to and activation of sphalerite by copper ions. The activation of sphalerite with Cu^{2+} is a much faster process than the activation of pyrite and may explain the relative increase in sphalerite vs pyrite flotation.

This indicates that long aeration stages prior to selective chalcopyrite flotation stages may be detrimental to copper/zinc selectivity, however maximum copper recovery requires a minimum of -150mV. Extremely long aeration stages (required to reach Ep levels of +25mV), caused the rougher concentrate grade to drop (from 9.0 to 6.9%Cu) as Cu/Zn and Cu/Fe selectivity was reduced.

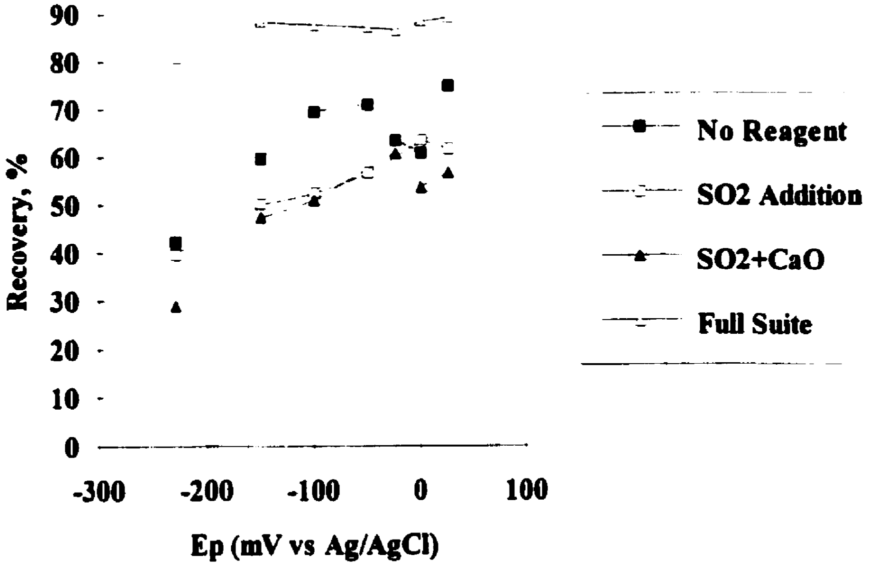

Figure 17. Cu Recovery vs Ep (Air Flotation)

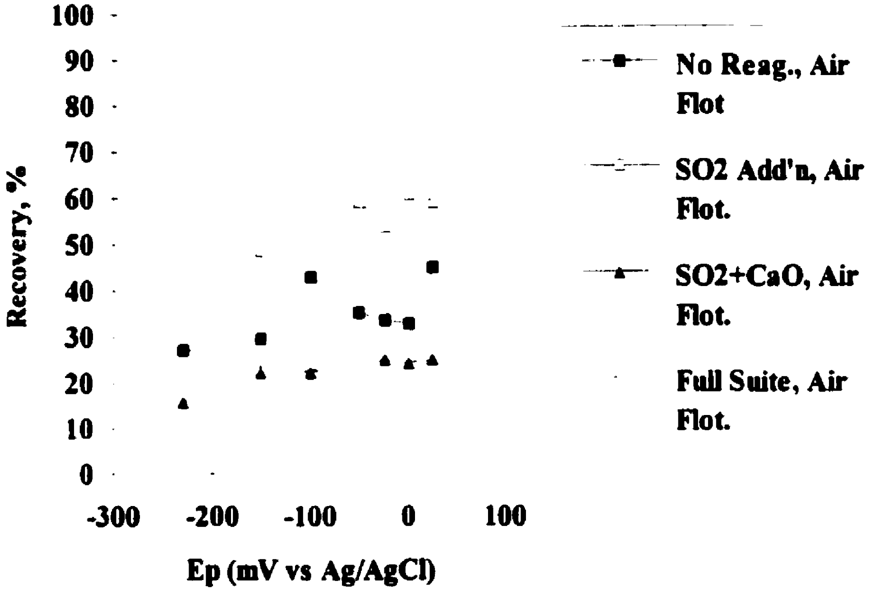

Figure 18. Zn Recovery vs Ep (Air Flotation)

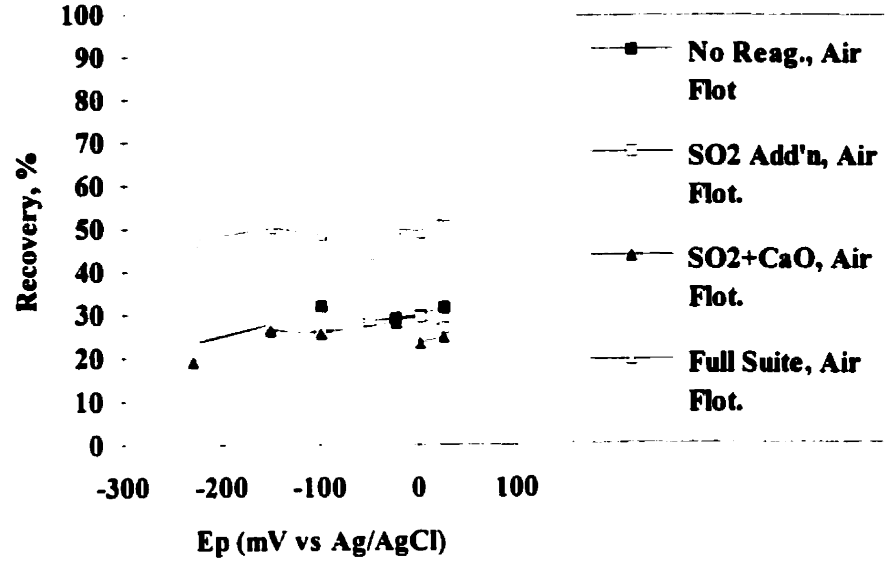

Figure 19. Fe Recovery vs Ep (Air Flotation)

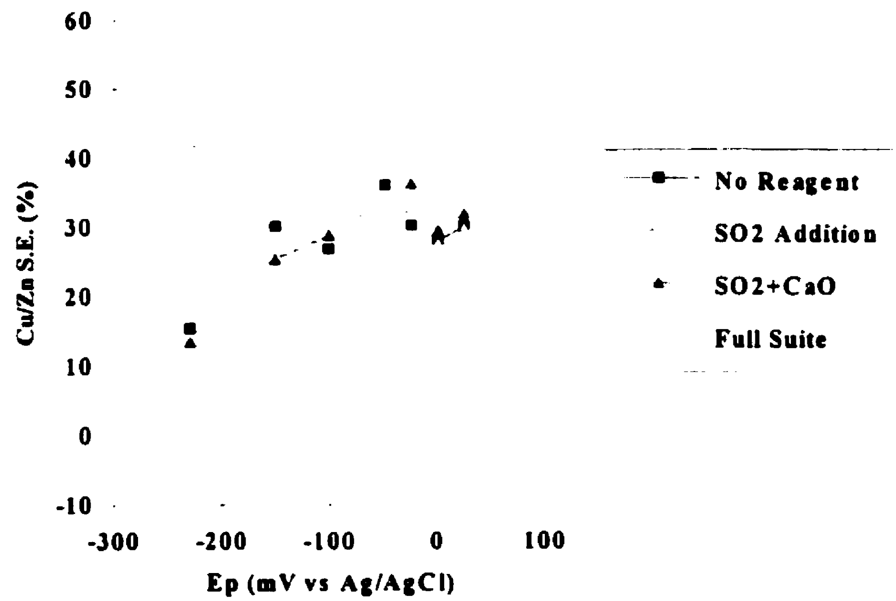

Figure 20. Cu/Zn Separation Efficiency vs Ep (Air Flotation)

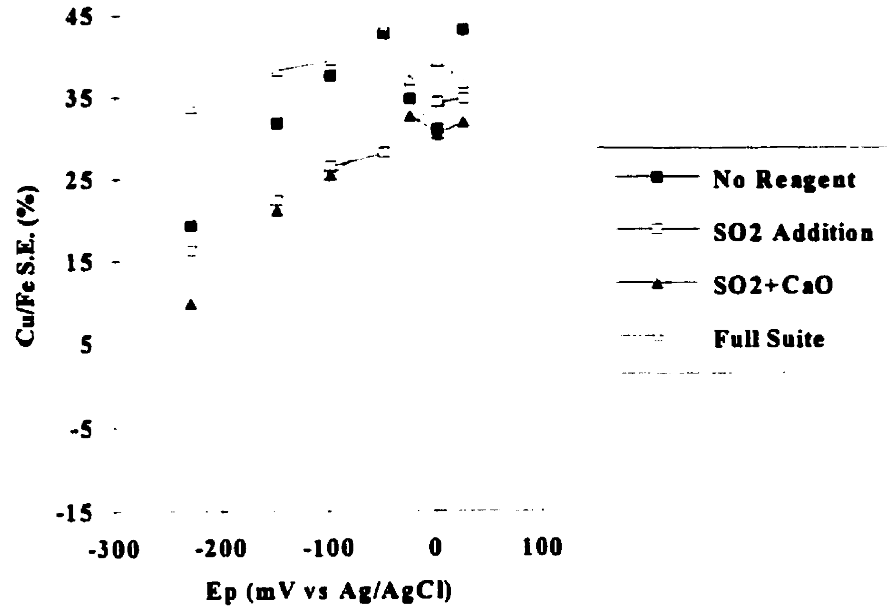

Figure 21. Cu/Fe Separation Efficiency vs Ep (Air Flotation)

6.3.3 Nitrogen vs Air Flotation

The same trends as discussed in the previous section exist with nitrogen as a flotation gas. However, some observations may be made between the two flotation gases.

Firstly, flotation with nitrogen produced lower copper, zinc and iron recoveries for the same initial Ep level (see Figure 22 - Figure 24). This indicates that while aeration prior to collector addition is important, collector will continue to adsorb if oxygen is provided during flotation. The decreased recoveries of chalcopyrite occurred primarily in reagent schemes not including collector, which indicates the addition of collector, as mentioned previously, reduces the sensitivity of the mineral surfaces to oxygen requirements. As seen in Figure 22, the recovery of copper was similar for both flotation gases above -25 mV (full suite). This then, is the pulp potential level at which "efficient" collector adsorption occurs. With air as a flotation gas, this effect was masked, as recoveries were constant from -150 to +50mV. Nitrogen, then is a better flotation gas for the determination of the pulp potential window for selectivity.

Copper/zinc and copper/iron selectivities were generally higher with N_2 as a flotation gas than with air (compare Figure 20/Figure 21 with Figure 25/Figure 26).

Increased copper recoveries were noted at -150 mV when air was the flotation gas and at -25 mV when N_2 was the flotation gas. This was consistent for all reagent schemes. The initial pulp potential level, i.e. the level at which collector is added, does not necessarily determine final recoveries if air is the flotation gas. Subsequent aeration will continue to provide the oxygen required by the system.

It is interesting to note that copper rougher flotation in the Kidd Creek plant occurred between -25 and 0mV. This measurement was taken in the head tank prior to copper flotation. If similar aeration occurs in the industrial cells as the laboratory cells then it may be advantageous to reduce, if possible, the level of the pulp potential prior to flotation. The increase in pulp potential from -150mV to -25mV does not increase copper recovery, and selectivity against sphalerite suffers (this when air is the flotation gas).

The minimum pulp potential required for maximum chalcopyrite recovery and grade is therefore between -50mV and -25mV. If air is the flotation gas, the pulp potential level at reagent addition may be lower as additional aeration during the flotation stage will allow this pulp potential level to be achieved.

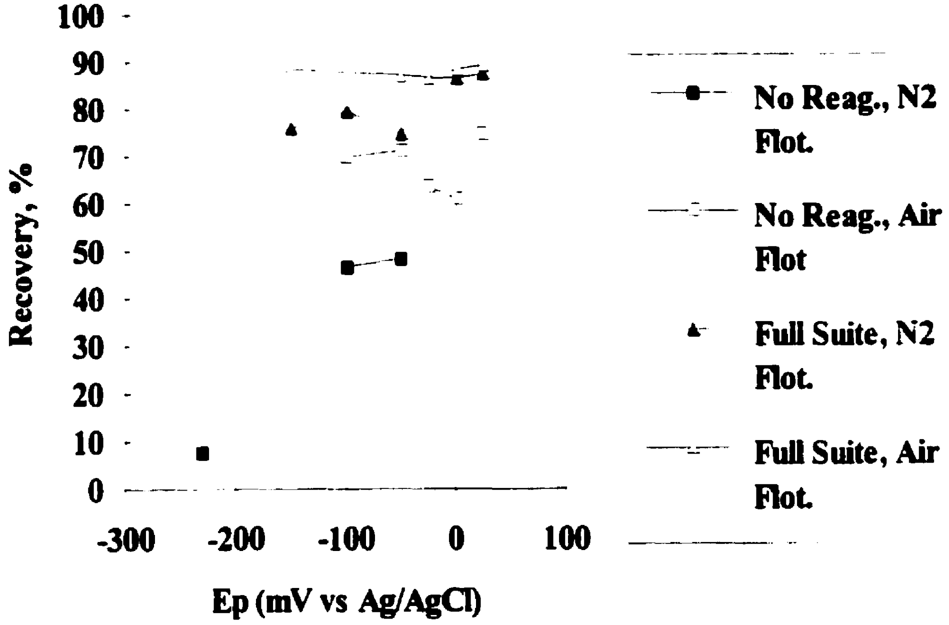

Figure 22. Cu Recovery vs Ep (Air vs N_2 Flotation)

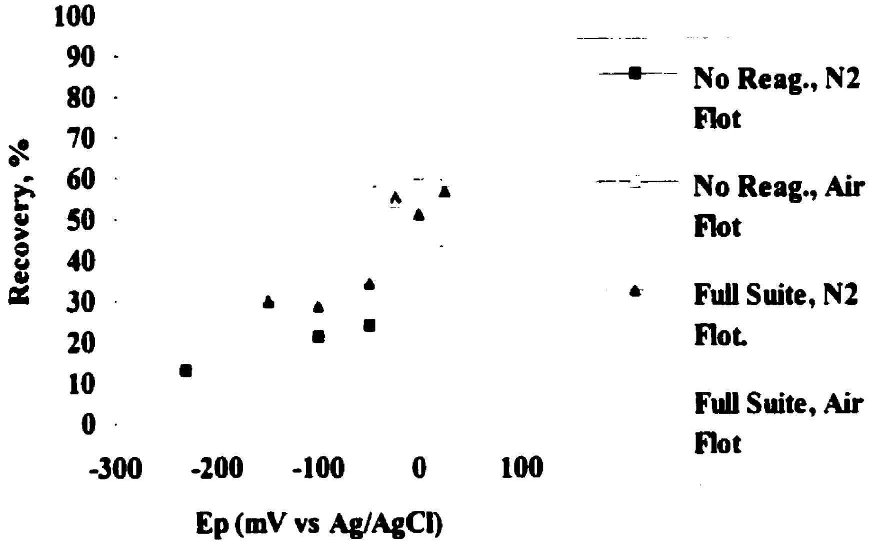

Figure 23. Zn Recovery vs Ep (Air vs N_2 Flotation)

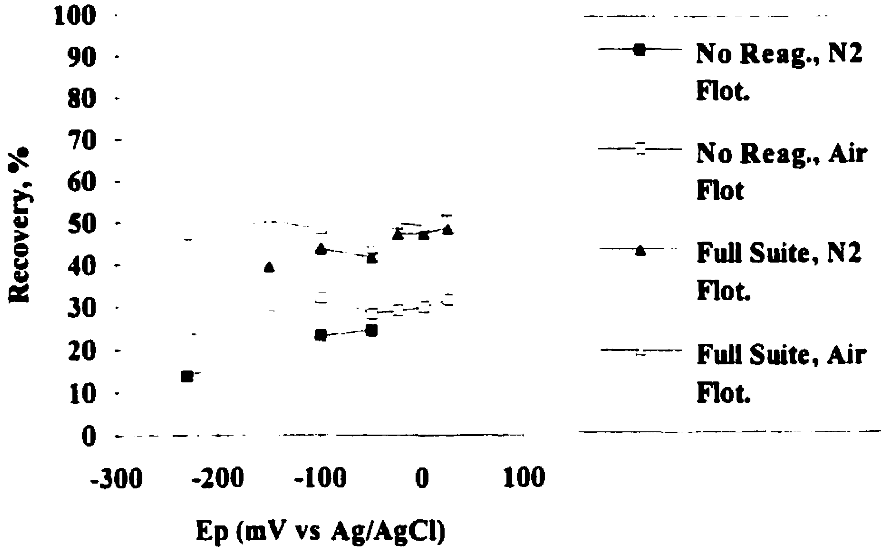

Figure 24. Fe Recovery vs Ep (Air vs N_2 Flotation)

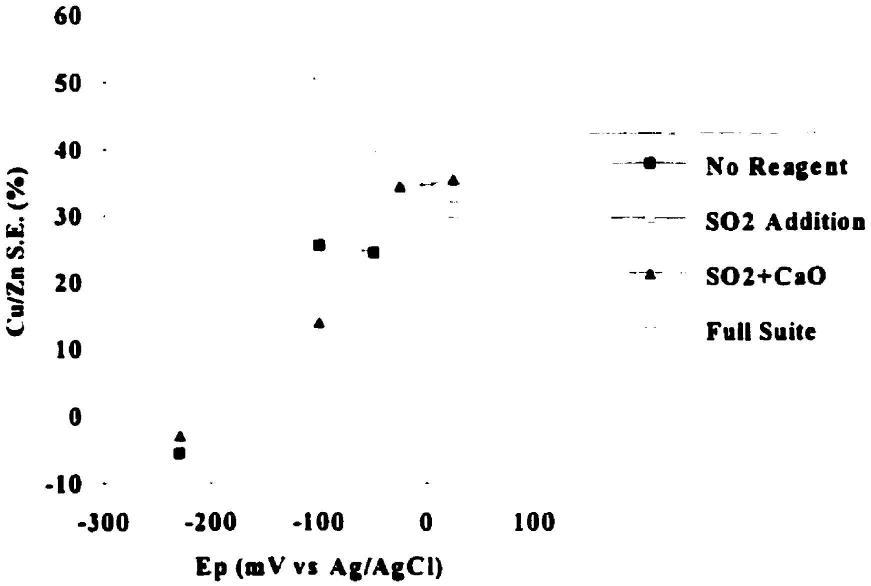

Figure 25. Cu/Zn Separation Efficiency vs Ep (N_2 Flotation)

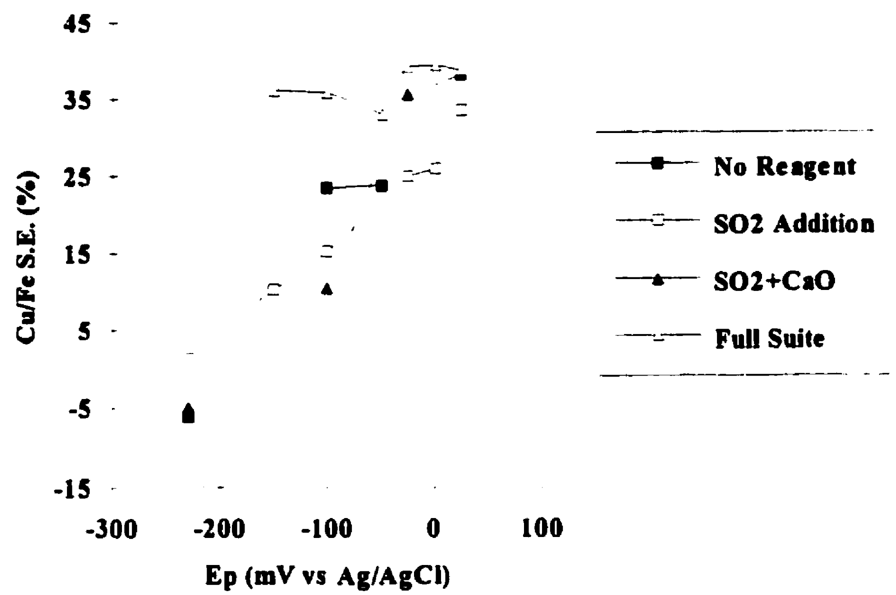

Figure 26. Cu/Fe Separation Efficiency vs Ep (N_2 Flotation)

6.4 E_m vs Pulp Potential

The factor E_m was calculated as mg metal extracted per gram solid. E_m could therefore be considered analogous to "grade" of the metals extracted. If E_m is related to recovery, then it may provide some indication of how the amount of surface species affect the hydrophobicity of the surface. The sample used to calculate E_{mfeed} was taken after aeration and reagent addition. It is the sum of the E_m value for the three cations measured: Pb, Fe and Zn.

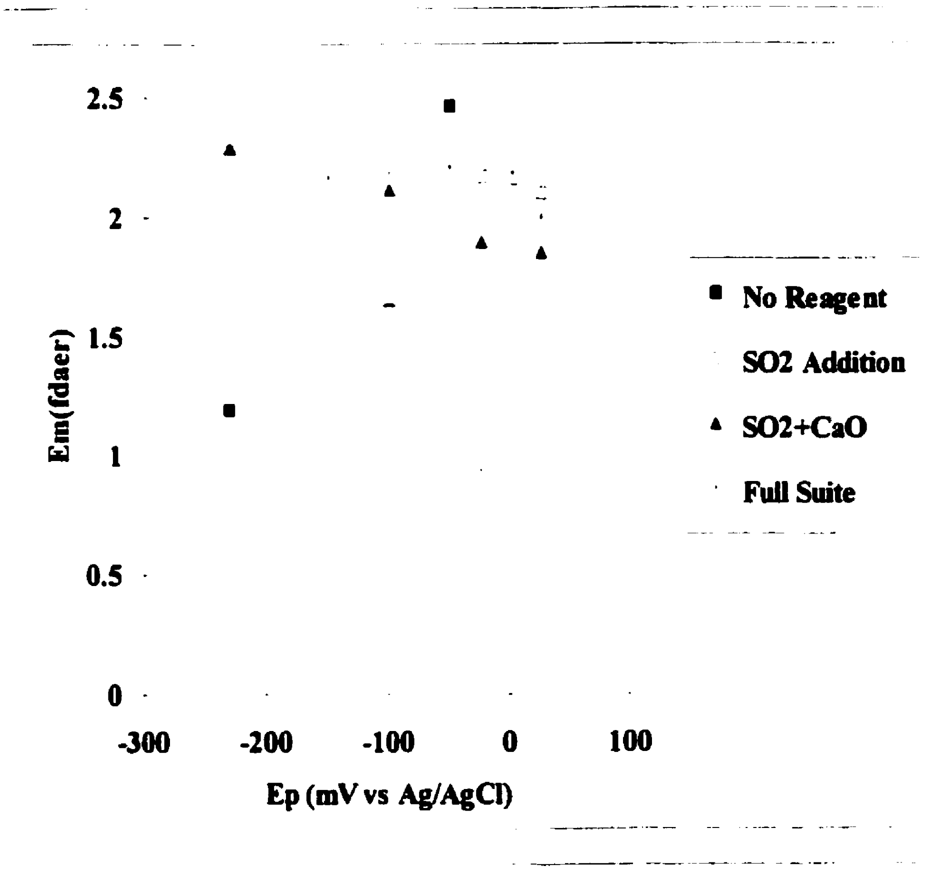

Figure 27. $E_{m(total)}$ After Aeration and Reagent Addition

As seen from the data in Table 5, iron is the predominant extracted metal. There exists a general downward trend in total extraction towards the higher pulp potential levels, perhaps due to a steady transformation to more stable oxide surface products which are more resistant to extraction. The total amount extracted from the no reagent, SO_2 and full suite reagent schemes was similar. A small drop in extraction was indicated for samples in the SO_2 and lime reagent scheme.

6.5 $Em_{(t-c)}$ vs Pulp Potential

This parameter represents the difference in extractablity between the tails and concentrates from flotation (Figure 28 to Figure 31). For all reagent suites except those with collector, $E_{m(t-c)Fe}$ was negative at pulp potentials lower than approximately 100mV. This implies that, per gram, more extractable iron exists in the concentrate than in the tailings. With no reagent addition, the amounts of extractable iron are similar in both the concentrate and tails across the examined pulp potential range. A dramatic change occurs with the addition of SO_2 with both N_2 and air as flotation gases. At the lower pulp potential levels, the $E_{m(tail)}$ is significantly lower than the concentrate. At approximately -50 mV (N_2) and 0 mV(air) the relative amounts of surface extractable iron are equal. Above these pulp potential levels, the $E_{m(conc)}$ is lower than that of the tail. This is also the potential level at which copper recovery reaches its maximum, which is also true of the non-reagent case. This is explained by the dual action of SO_2 as either an oxidant or reductant dependent on the pulp potential. If the amount of surface extractable iron on the mineral surface dictates floatability, then several questions arise:

(1) In what form do these surface species appear, and how do they impact floatability?

(2) Does the nature of the surface species change over the pulp potential range, such that species which are hydrophobic at -200 mV, become less so at 25 mV?

While these trends are most evident in the SO_2 and SO_2/lime reagent schemes, the addition of collector causes the opposite trend (with $E_{m(tail)}$ still larger than $E_{m(conc)}$ in all cases). At the same time, recoveries become relatively constant across the pulp potential range. The adsorption of collector, then, might displace surface species or adsorb primarily to minerals which have few surface extractable species. If this is true, then it is possible that aeration, or reagent addition serves to selectively alter the surface of mineral types.

Since surface reactivity varies from mineral to mineral, it is possible that surface species develop preferentially on certain mineral types. At higher pulp potentials, $E_{m(t-c)Fe}$ was slightly positive. There was little to no change in $E_{m(tail)}$ indicating that the extractability of species was inhibited in some way on those minerals reporting to the concentrate. It remains to be seen whether prolonged oxidation of iron surface species on mineral particles reduces their extraction; however, this seems likely. The addition of collector also decreases the amount of extractable iron in the concentrate, perhaps by displacing them from the surface (Smart, 1991). Addition of collector caused the extractability to remain close to constant at the higher pulp potential levels.

Lead and zinc exhibited negative $E_{m(t-c)}$ values for all suites not including those with collector. Both metals exhibited positive $E_{m(t-c)}$ values for reagent suites including collector which supports the hypothesis that collector either inhibits extraction of surface species, or displaces them prior to EDTA extraction.

There was little difference in $E_{m(t-c)}$ whether air or nitrogen was the flotation gas.

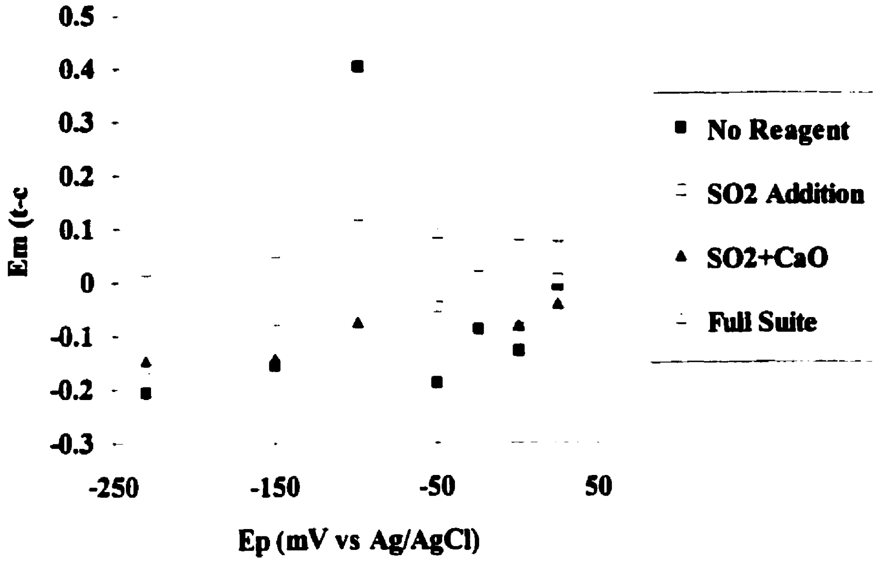

Figure 28. $Em_{(t-c)Pb}$ vs Ep (Air Flotation)

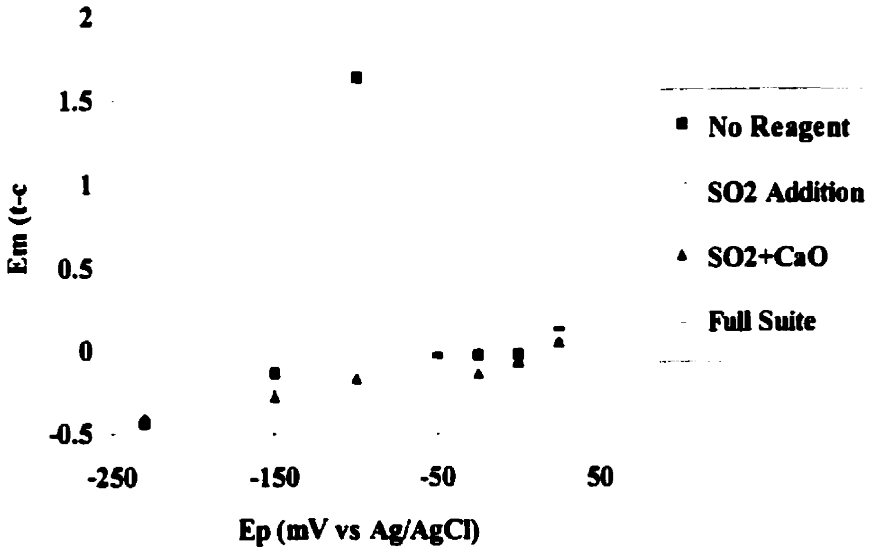

Figure 29. $Em_{(t-c)Zn}$ vs Ep (Air Flotation)

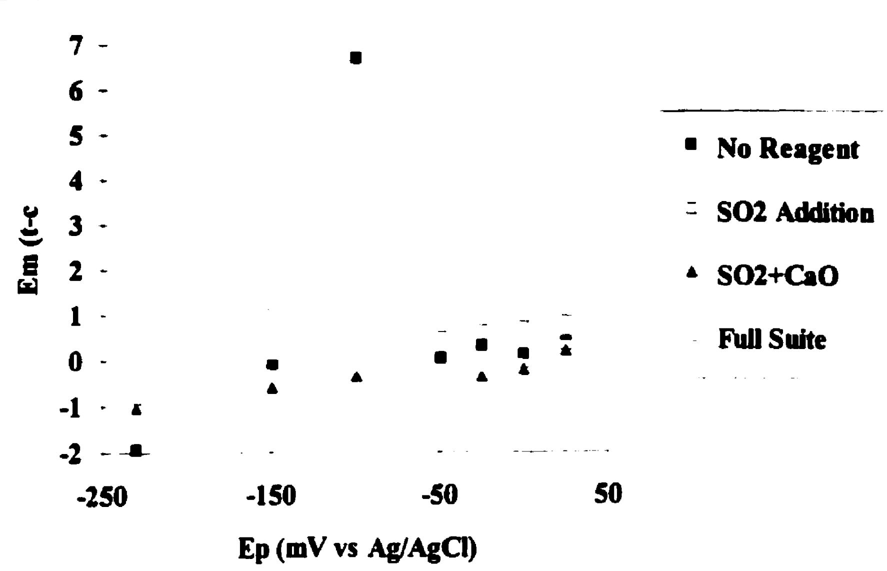

Figure 30. $Em_{(t-c)Fe}$ vs Ep (Air Flotation)

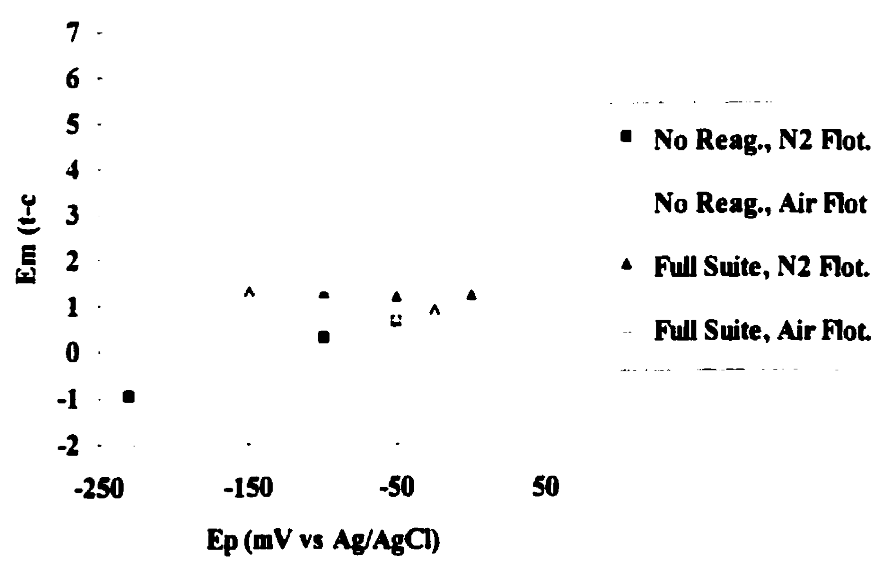

Figure 31.$Em_{(t-c)Fe}$ vs Ep (Air vs N_2 Flotation)

6.6 $E_{m(t-c)}$ vs Separation Efficiency

The separation efficiency (SE) is a measure of the selectivity between metals and is calculated as %Cu recovery - %Zn recovery (Cu/Zn SE) or %Cu recovery - %Fe recovery (Cu/Fe SE). When $Em_{(t-c)}$ is compared to the separation efficiency, a relationship between the surface species and the metallurgical response can be obtained. As shown in Figure 32 to Figure 37, as the difference between the extractability of tailings and concentrates increases, so does the separation efficiency for both Cu/Zn and Cu/Fe. This reinforces the work performed by Shannon and Trahar (1986) who found that the removal of surface species by EDTA increased the floatability of chalcopyrite. Possibly the decrease in the production of these species can be effected by collector. If this is so, then one area of future research might be the comparison of different collector types (xanthates, thiocarbamates, dithiophosphates, etc) in order to ascertain their effect on selectivity and the $E_{m(t-c)}$ parameter.

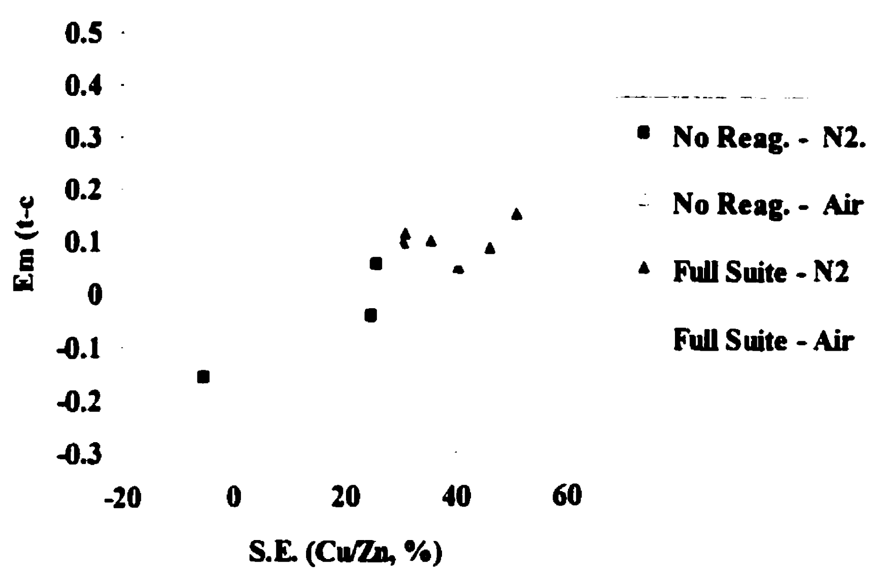

Figure 32. $Em_{(t-c)Pb}$ vs Cu/Zn S.E.

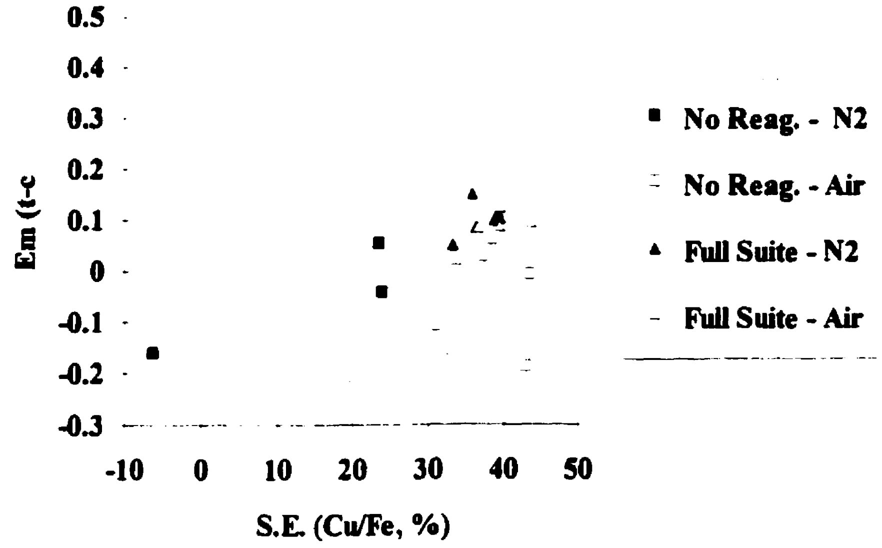

Figure 33. $Em_{(t-c)Pb}$ vs Cu/Fe S.E.

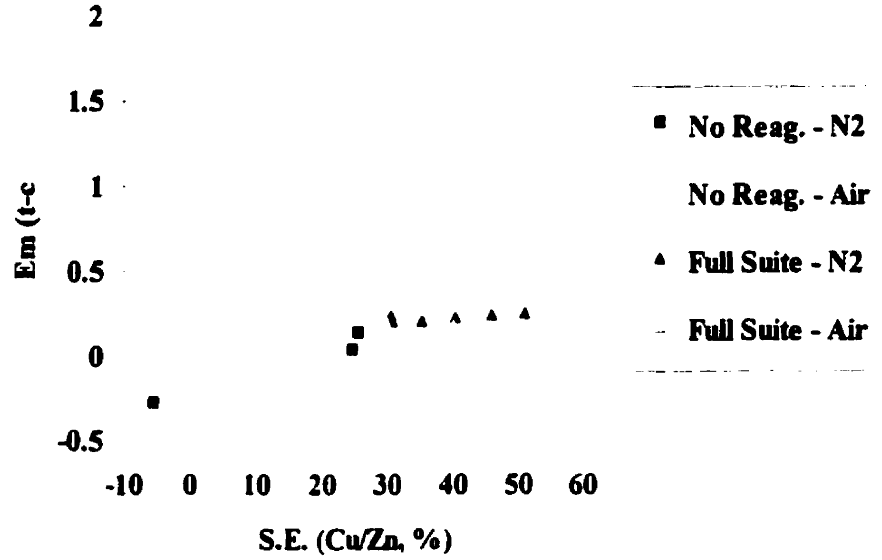

Figure 34. $Em_{(t-c)Zn}$ vs Cu/Zn S.E.

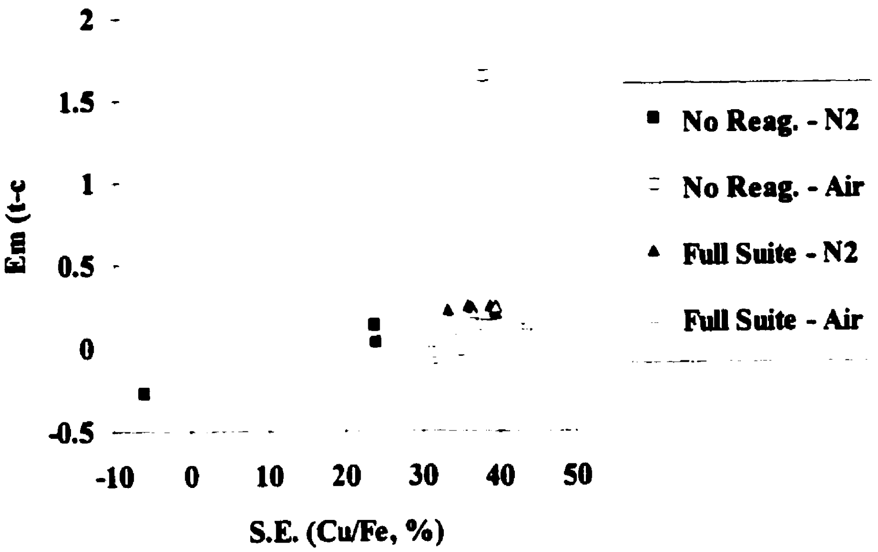

Figure 35. $Em_{(t-c)Zn}$ vs Cu/Fe S.E.

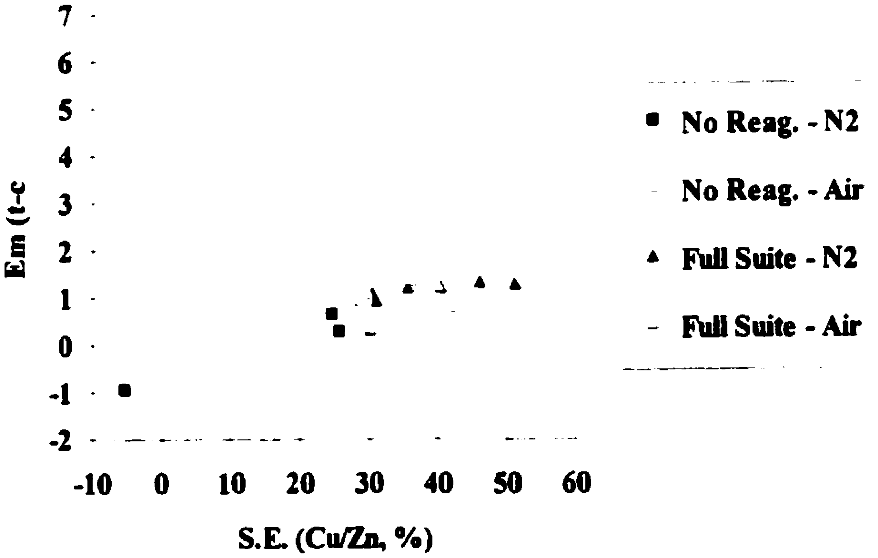

Figure 36. $Em_{(t-c)Fe}$ vs Cu/Zn S.E.

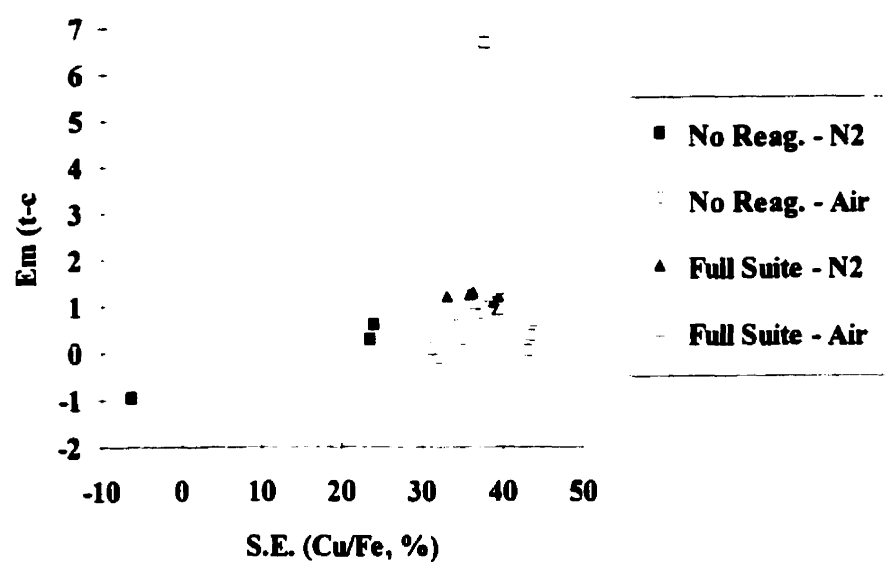

Figure 37. $Em_{(t-c)Fe}$ vs Cu/Fe S.E.

6.7 $E_{m(fdaer\text{-}fd)}$ vs Ep

Shown in the next set of figures are the differences in the E_m values for the feed before and after aeration and reagent addition ($E_{m(fdaer\text{-}fd)}$). This parameter represents the difference in extractability after aeration and reagent addition. The impact of surface oxidation on the surface is shown by a downward trend in the amount of surface extractablity of iron as aeration or pulp potential increases. These trends do not appear for lead and are less noticeable for zinc, except for the full suite case.

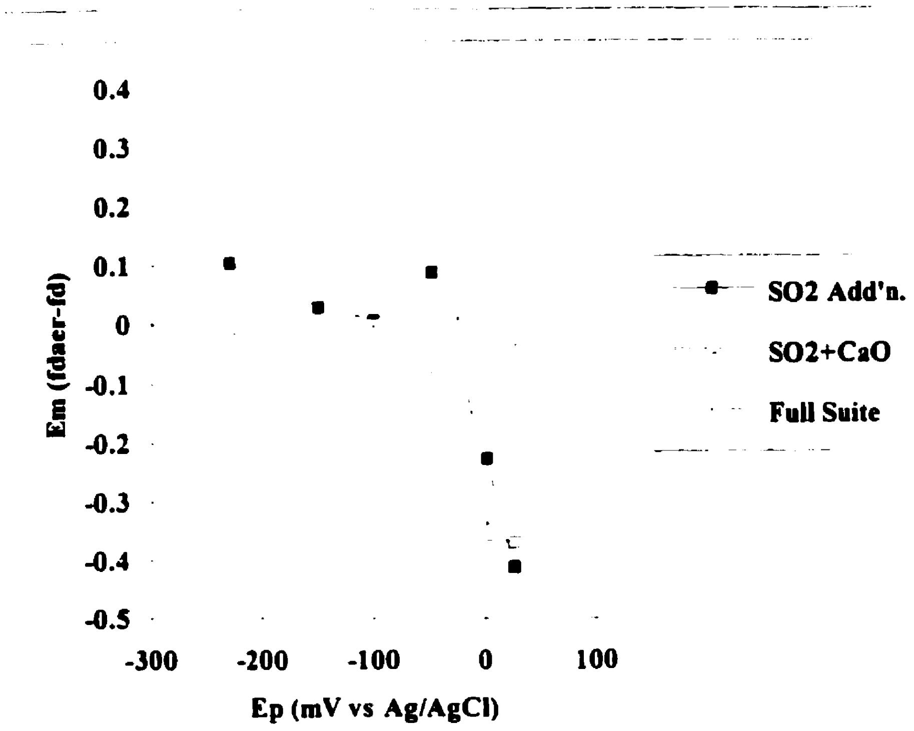

Figure 38. $E_{m(fdaer\text{-}fd)Fe}$ vs Ep-Air Flotation

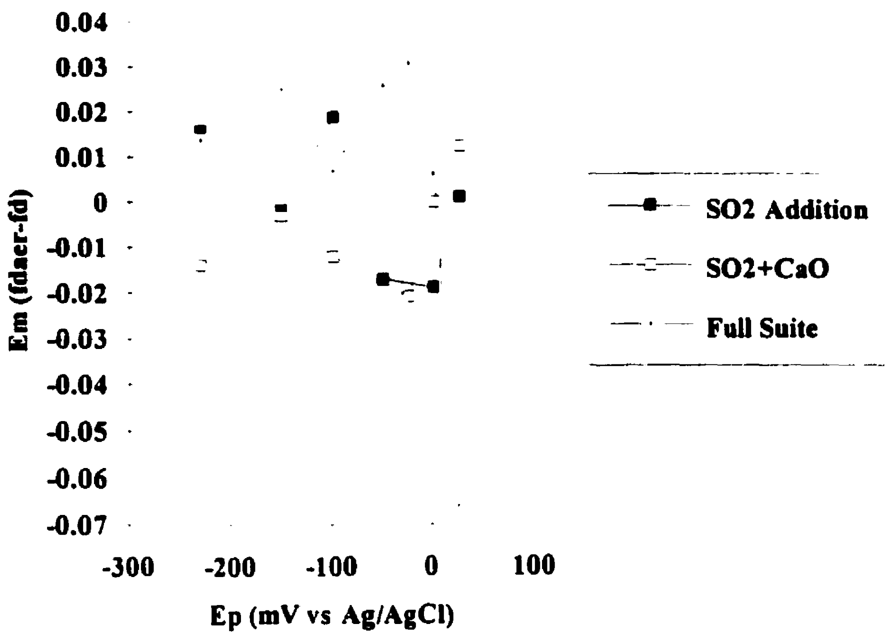

Figure 39. $Em_{(fdaer-fd)Pb}$ vs Ep-Air Flotation

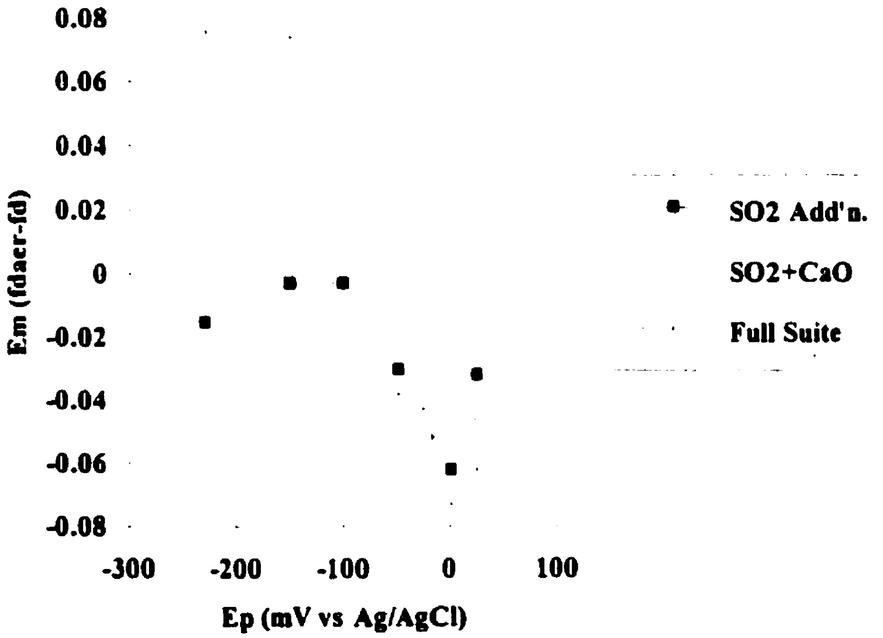

Figure 40. $Em_{(fdaer-fd)Zn}$ vs Ep-Air Flotation

6.8 $E_{m(fdaer\text{-}fd)}$ vs S.E.

The factor $E_{m(feed)}$ represents the absolute extraction from the feed before aeration. The subsequent aeration and reagent addition to the slurry would change the character of the surface. The factor $E_{m(fdaer\text{-}fd)}$ measures this change. The next set of Figures (Figure 41-Figure 42) show the relationship between this and the separation efficiency. While the trend for Cu/Zn selectivity is less noticeable, there is a clear relationship between the change in the extractable species and the separation efficiency of copper and iron. As the factor $E_{m(fdaer\text{-}fd)}$ drops (in fact, goes to negative) the selectivity increases. It may be that aeration or the reagents act to decrease the amount of extractable species, which in turn allows for better collector adhesion and/or provides for less competition from hydrophilic species.

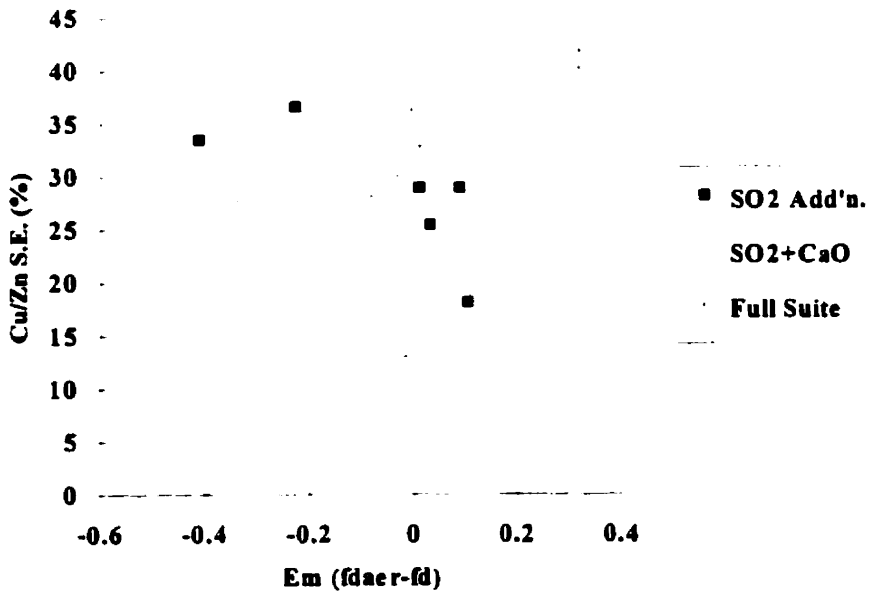

Figure 41. Separation Efficiency (Cu/Zn) vs $E_{m(fdaer\text{-}fd)Fe}$ - Air

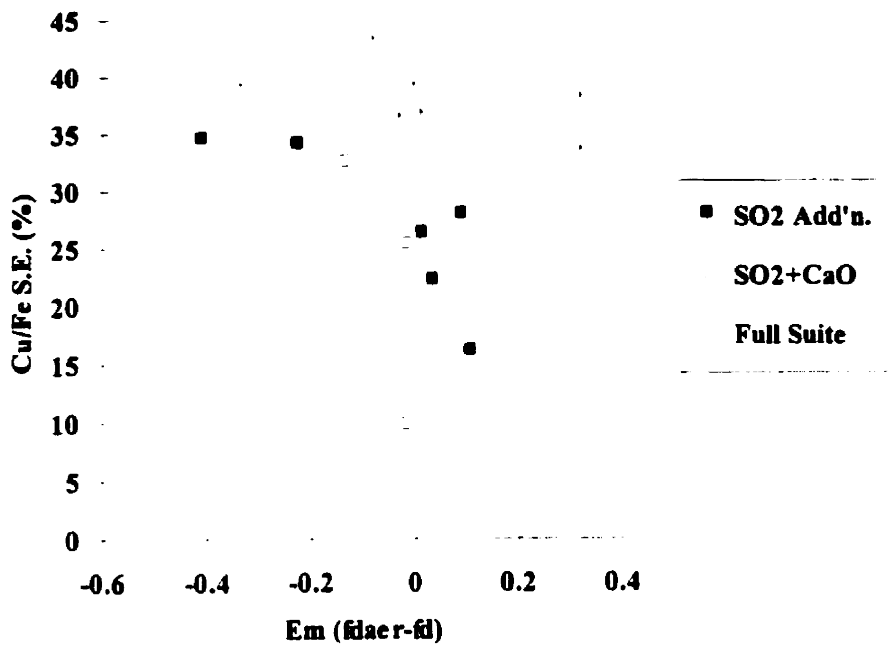

Figure 42. Separation Efficiency (Cu/Fe) vs $E_{m(fdaer-fd)Fe}$ - Air

6.9 E_s vs Ep

While E_m represents grams of metal extracted per gram of sample (analogous to grade) E_s is equal to grams of metal extracted per gram of metal in the sample (analogous to recovery). Shown in Figure 43-Figure 45 are the E_s values vs pulp potential. Extraction decreases above -100 mV. The most notable result of this determination is the large proportion of lead recovered from the feed samples. Up to 25% of the lead was present as soluble surface species.

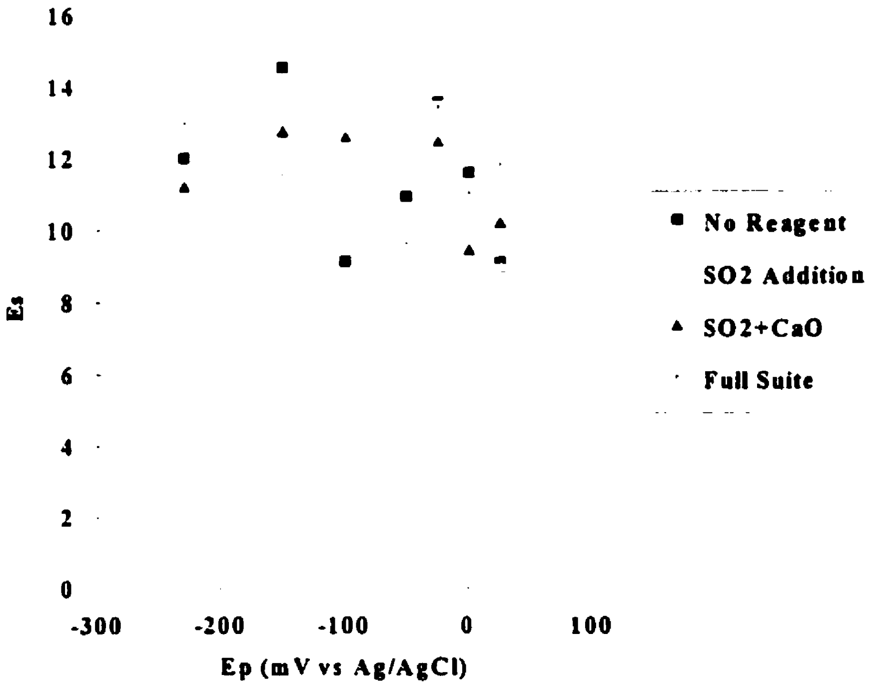

Figure 43. Ep vs E_{sFe}

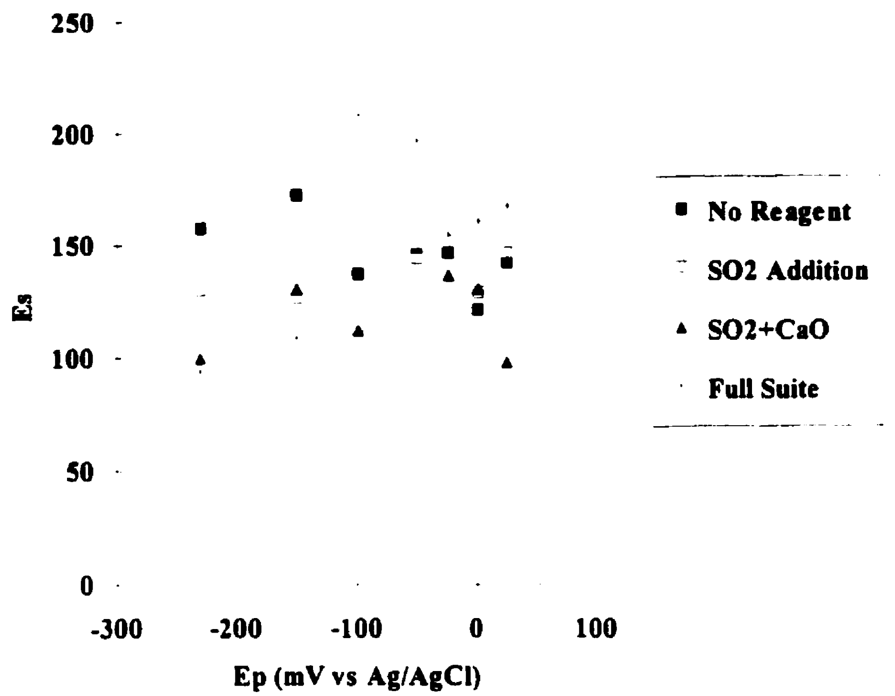

Figure 44. Ep vs E_{sPb}

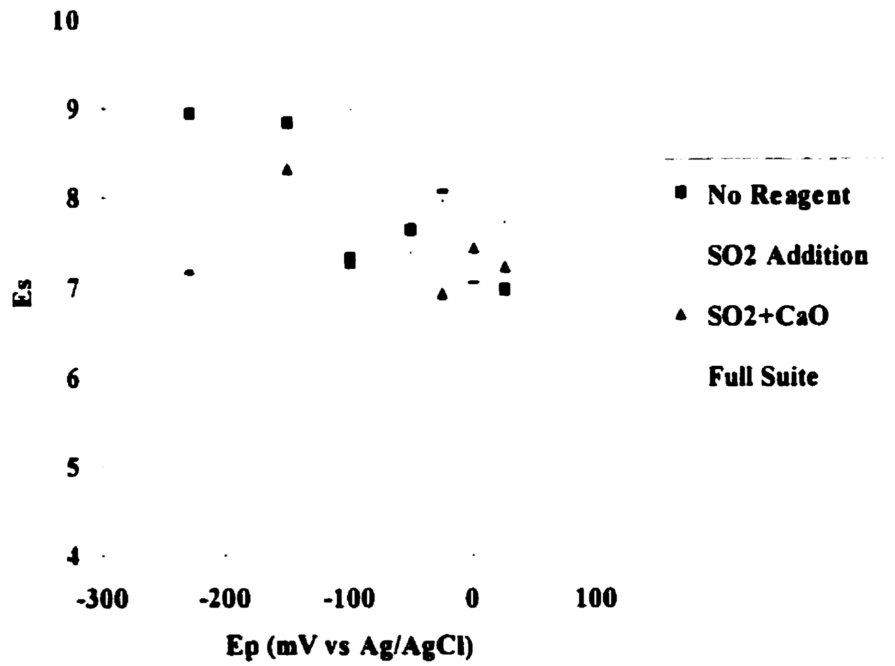

Figure 45. Ep vs E_{sZn}

6.10 Dynamic Dissolved Oxygen

Measurements of the uptake of oxygen by the mineral slurry were conducted for each test. Presented in Figure 46 are the dynamic dissolved oxygen values for four reagent schemes. It should be noted that the two full suite data sets are repeats, as are the SO_2 data sets. While the full suite data sets seem to repeat quite well, there is a larger discrepancy for the SO_2 sets.

It is expected that as pulp potential increases, the DDO will decrease as mineral activity decreases. That is, as the mineral surfaces are exposed to more oxidizing conditions, their ability to consume oxygen drops. This trend, however, was not noted in this testwork.

There appears to be a trend upwards in DDO with increased pulp potential when collector is present until a maximum is reached at -50mV. There then appears to be a slight decrease in the rate of consumption of oxygen. Interestingly, the pulp potential value at the highest DDO value is the same pulp potential value which showed the maximum copper recovery and the optimum copper/iron SE.

The scatter between the same reagent suite with different flotation gases is large for the suite with SO_2.. This is thought to be related to the same effect seen during the analysis of copper recovery with air and nitrogen. It appears that collector acts to "buffer" the surface to any small changes in aeration, somehow controlling the adsorption of oxygen by the minerals.

DDO is compared to aeration time in Figure 47, an improved trend appears. Large changes and a high dispersion are noted for the short aeration times. After 500 seconds of aeration, dispersion decreases as does the trend of DDO.

It was hope that DDO could be used to compare the activity of the mineral surface to Ep and metallurgical response. As shown, there is a trend, but the scatter is large. In order to further test any correlation the sensitivity of the data acquisition system would need to be improved (frequency of measurement) in order to accurately calculate the change in dissolved oxygen content at the point of cessation of aeration.

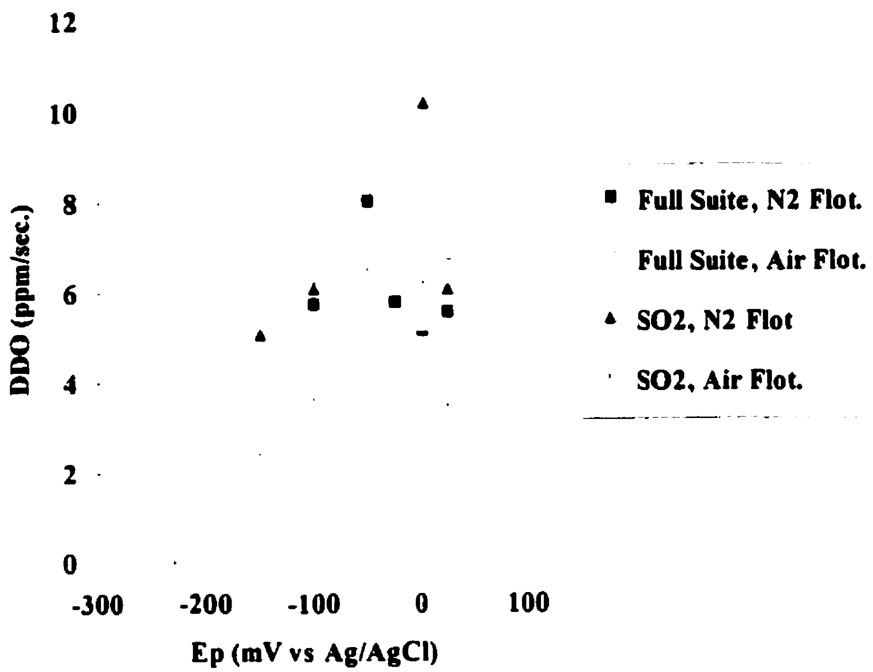

Figure 46. Ep vs Dynamic Dissolved Oxygen

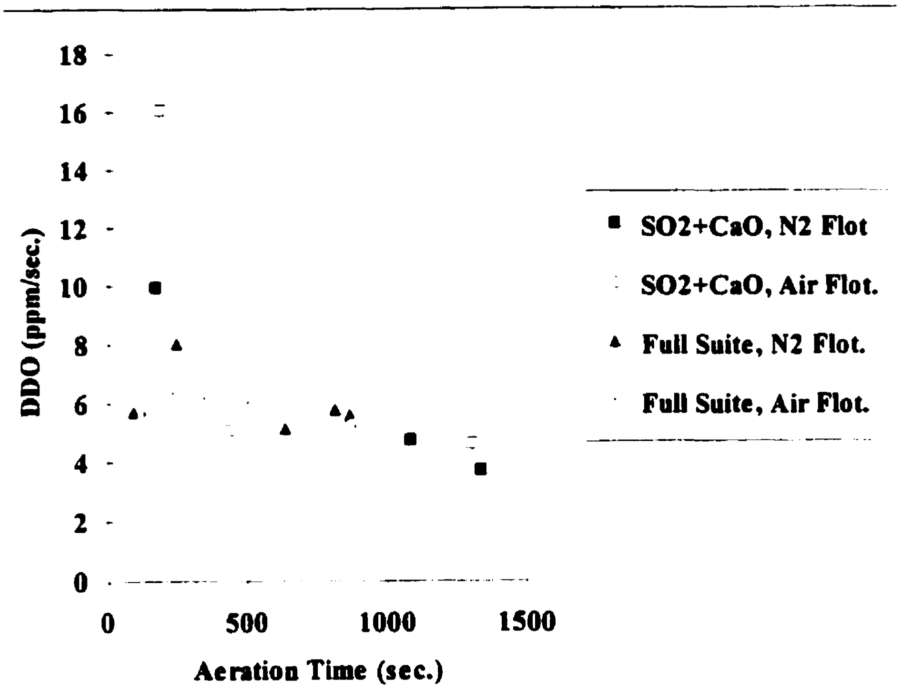

Figure 47. Aeration Time vs Dynamic Dissolved Oxygen

6.11 Plant Surveys

The data collected over a one-month period were plotted against the Pourbaix diagram for the iron/water/oxygen system (Figure 51). It is suggested that the transition from Fe^{2+} to $Fe(OH)_2^+$ is the dominant one, with ferric ions appearing only in the third cleaner. The hypothesis that surface ions of iron are controlling the electrochemical potential would need to be proven through the use of XPS or LIMS.

It can be noted from these data that while primary ball mill discharge pulp potentials show a high level of dispersion, the primary rougher and 3rd cleaner Ep levels are much more consistent. This may be explained by the low Ep values in the primary ball mill discharge stream. Small fluctuations in air entrapment may cause large fluctuations in the pulp potential. The flotation feed, on the other hand, appears to be buffered to changes in the degree of air entrainment due to pumps, hydrocyclones, etc. It is possible that the degree of oxidation of the mineral surface (which partly dictates pulp potential) at the moment of rougher flotation has lowered the sensitivity of the surface to oxygen in the system (a buffering effect of sorts). A large increase or decrease in aeration time would therefore be necessary to markedly change the pulp potential in the flotation circuit. It has been noted by researchers in this area that the majority of flotation plants operate "surprisingly" close to (or at) the optimum pulp potential for recovery and selectivity of the valuable mineral in question. Upon further reflection , however, it is perhaps understandable that flotation plants would need to operate close to the optimum pulp chemistry for their particular system in order to achieve successful mineral separations. The process of achieving these flowsheets and reagent schemes is one of trial and error with historical knowledge as a base. The procedure is made more difficult due to the lack of fundamental information of the flotation system and is therefore a longer process than would be the case if a model of the flotation process could be developed.

Pourbaix Diagram Equations (Pourbaix, 1974)

Equation 6: $Fe^{2+} + H_2O \rightarrow Fe(OH)_2^{+} + 2H^{+} + é$

[E°=1.191-0.1182*pH]

Equation 7: $HFeO_2^{-} + H^{+} \rightarrow Fe(OH)_2^{+} + é$

[E°=-0.675+0.0591*pH]

Equation 11: $Fe(OH)_2^{+} + 2H_2O \rightarrow FeO_4^{2-} + 6H^{+} + é$

[E°=1.559-0.1182*pH]

Comparisons between plant and laboratory extractions are shown in Figure 48 to Figure 50. Extractions for zinc, iron and lead in the laboratory were approximately double that in the plant. This may be due to a reduced aeration time in the plant to achieve the same pulp potential. The pulp chemistry in the plant is likely different to that in the laboratory due to the chemistry of recirculating waer.

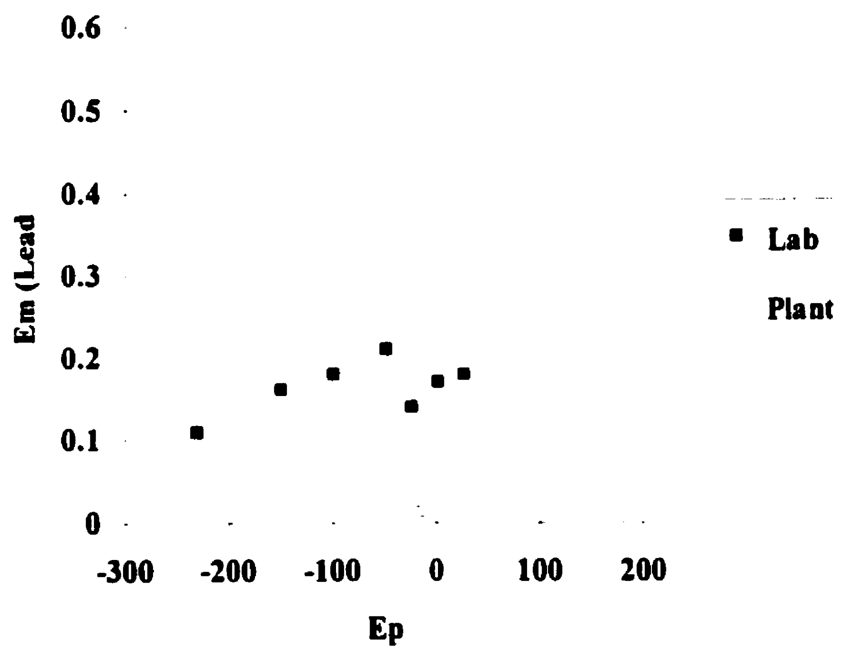

Figure 48. Plant vs Lab Extractions - Lead

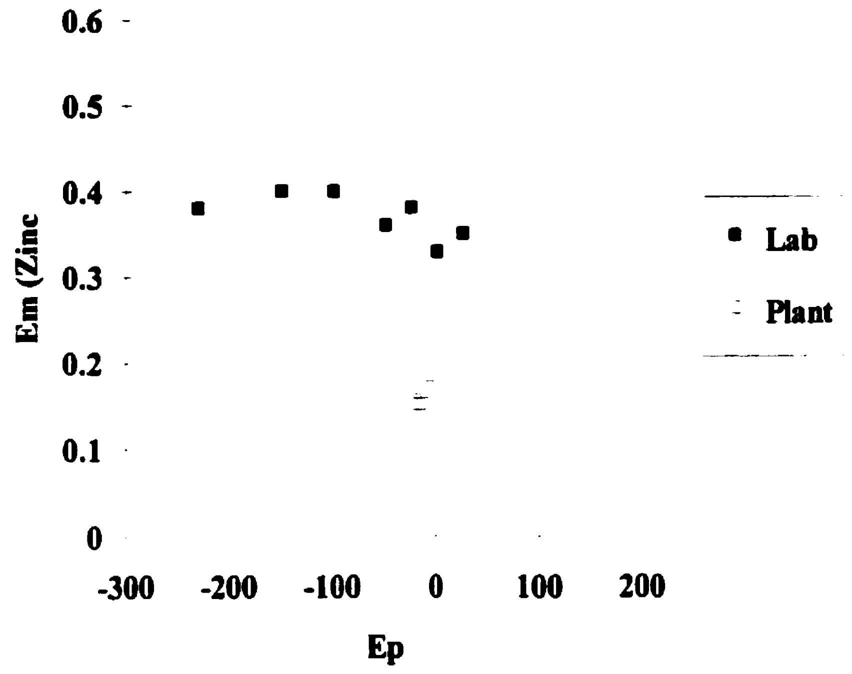

Figure 49. Plant vs Lab Extractions - Zinc

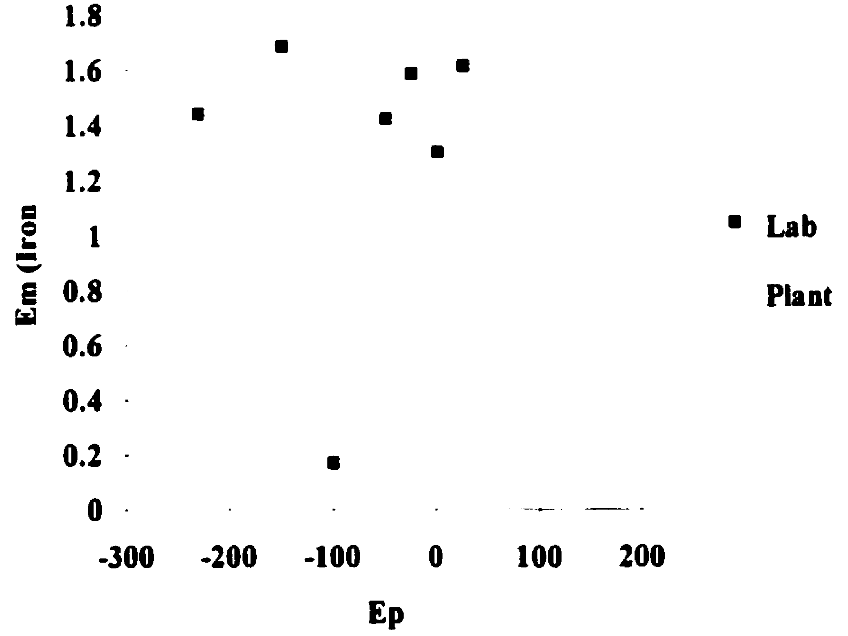

Figure 50. Plant vs Lab Extractions - Iron

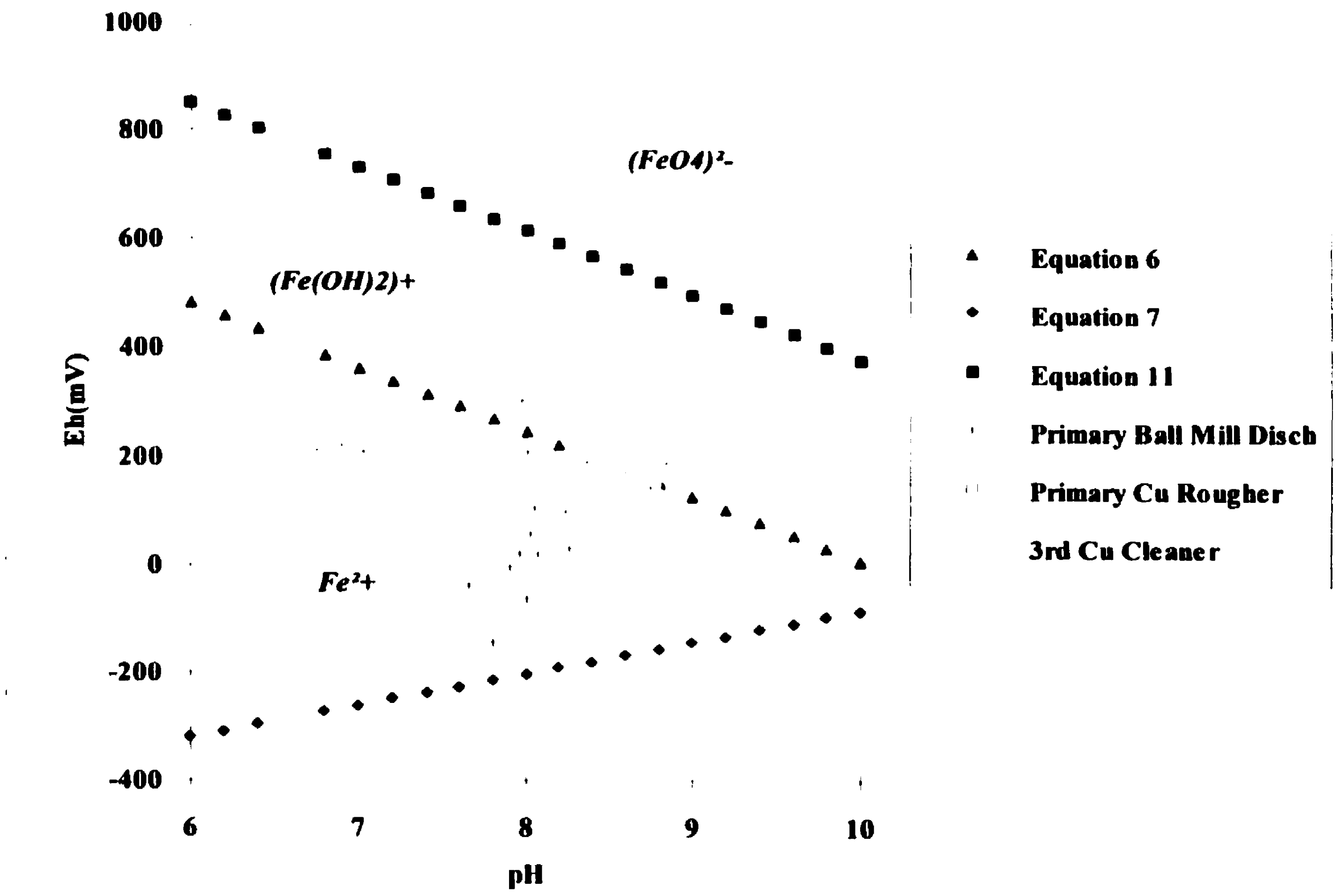

Figure 51. Pourbaix Diagram of Iron System from pH 6-pH 10.0 with Plant Survey Data

7.0 Conclusions and Recommendations for Future Work

1. Copper was not extracted by EDTA which may be due to its interaction with sphalerite. Similar studies with EDTA (Grano, 1990) have indicated that copper ions are extractable by EDTA, but this may only be the case when the amount of sphalerite and pyrite are negligible or insufficient to consume all the copper in the system.

2. The recovery of copper is related to pulp potential with a maximum being reached at -150mV (Ag/AgCl). However, the maximum separation efficiency, against zinc was reached at -230 mV, and against iron at -50mV.

3. Nitrogen had a negligible effect on the flotation of copper or its selectivity against zinc and iron. Its use, however, appears to give a more accurate response to pulp potential. Continued aeration during flotation, and subsequent increases in pulp potential, make correlation of pulp potential to flotation response difficult. Nitrogen therefore represents an inert alternative which does not appear to have an effect beyond serving as a vehicle for producing bubbles.

4. The parameters E_m and E_s were developed in order to quantify the relative amounts of extractable metals. They were defined as mg of metal extracted per gram of solid and mg of metal extracted per gram of metal, respectively.

5. The total extraction of metals decreased after aeration and reagent addition. Extractions were similar for all reagent suites.

6. $Em_{(t\text{-}c)Fe}$ values increased with pulp potential. This was mostly due to a reduction in the extractable species in the concentrate. As the concentrate taken for extraction represents only the first thirty seconds of flotation, a true balance would need to be performed using an extraction on the complete concentrate. Copper/iron SE increased with $Em_{(t\text{-}c)Fe}$ for the different reagent schemes.

7. While Em was calculated as mg extracted per gram of feed, the surface area of the products was not taken into account. It stands to reason that the amount of surface products would be related to the surface area available for their formation. In many instances the concentrate size analysis will vary significantly from the tailings. If this is the case for Kidd Creek, the extractions per unit area may not have been different between tail and concentrate, and the factor $Em_{(t\text{-}c)}$ would therefore be measuring only a difference in the area available for extraction. This is not likely given that $Em_{(t\text{-}c)Fe}$ appeared to be related to the separation efficiency. Further testwork in the area of EDTA extraction should be aimed at the comparison of extractions in different plant environments with varying plant feeds. In order to accomplish this task, the relative extractions with regard to surface area should be measured.

8. The dynamic dissolved oxygen showed a maximum at the same pulp potential level as the maximum copper recovery and copper/iron SE. It is not known how these parameters are related, however the construction of a more sensitive data acquisition system would allow for more accurate measurements of DDO, possibly solidifying the relationship.

9. Plant Ep levels correlated with those needed to achieve maximum copper recovery and copper/iron SE. Extractions from rougher feed and cleaner concentrate were similar to those measured in the laboratory.

10. Studies with EDTA have led to the conclusion that continuing oxidation of the mineral surface during EDTA extraction can corrupt the data. This oxidation can occur from oxygen present in the pulp or EDTA solution. This has led to the use of nitrogen purged EDTA solutions and pulps during EDTA extractions. Any further study in this area would require these precautions.

11. The study of pulp potential and EDTA extraction has shown significant correlation to metallurgical response. New areas of investigation derived from this thesis include:

(i) Comparison of EDTA data generated at different pulp potential for different plant feeds. A parameter including the surface area available for extraction would need to be employed. This parameter should then be correlated to metallurgical response.

(ii) Correlation of DDO to metallurgical response using a more sophisticated data acquisition system.

(iii) An investigation of the activation of pyrite or sphalerite by copper ions. It may be that different pulp potential or reagent conditions favor the adsorption of copper onto one or other mineral.

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Appendix

Test		17	22	22b	22c	Mean	Standard Error	Standard Deviation	Variance
Final Grade	Cu	10.79	7.74	7.89	8.17	8.65	0.72	1.44	2.07
	Zn	13.5	10.49	11.19	12.12	11.83	0.65	1.30	1.69
	Pb	0.47	0.46	0.49	0.63	0.51	0.04	0.08	0.01
	Fe	25.27	21.53	22.22	22.35	22.84	0.83	1.66	2.75
Final Recovery	Cu	74.8	65.76	63.75	64.9	67.30	2.53	5.07	25.66
	Zn	44.81	37.58	38.01	45.79	41.55	2.18	4.35	18.97
	Pb	69.13	61.51	66.23	81.41	69.57	4.25	8.50	72.17
	Fe	31.6	30.1	29.06	33.59	31.09	0.98	1.97	3.87
Em(feed)	Zn	0.356	0.363	0.319	0.333	0.343	0.0102	0.0204	0.0004
	Pb	0.147	0.137	0.122	0.14	0.137	0.0053	0.0105	0.0001
	Fe	1.246	1.303	1.184	1.355	1.272	0.0368	0.0736	0.0054
Em(conc)	Zn	0.292	0.362	0.378	0.372	0.351	0.0199	0.0399	0.0016
	Pb	0.177	0.207	0.172	0.173	0.182	0.0083	0.0166	0.0003
	Fe	0.83	1.169	1.253	1.297	1.137	0.1058	0.2116	0.0448
Em (tail)	Zn	0.4	0.377	0.401	0.388	0.392	0.0057	0.0113	0.0001
	Pb	0.169	0.145	0.148	0.149	0.153	0.0055	0.0110	0.0001
	Fe	1.213	1.247	1.342	1.329	1.283	0.0313	0.0627	0.0039

Sept. 1/92 Test: 11

Pulp Potential: -230
(mV vs Ag/AgCl)
Flotation Gas: Nitrogen

Stage	Reagents (g/t)						Time (min)		
	CaO	3418	MIBC	CuSO4	SEX	SO2	Grind	Cond	Froth
Grind	-	-	-				43		
Rougher-1	-	-	10	-	-	-		-	0.5
Rougher-2	-	-	-	-	-	-		-	0.5
Rougher-3	-	-	-	-	-	-		-	1
Rougher 4	-	-	-	-	-	-		-	2
Condition	y	-	-	-	-	-			
Condition	-	-	-	415	-	-		1	
Rougher	-	-	-	-	60	-			1

Metallurgical Balance

Product	Weight		Grade,%				% Recovery			
	g	%	Cu	Zn	Pb	Fe	Cu	Zn	Pb	Fe
Cu Ro Conc 1	15.1	1.51	2.39	7.82	1.34	24.0	1.4	2.2	12.8	2.4
Cu Ro Conc 2	18.8	1.89	2.35	7.52	1.35	24.6	1.7	2.6	16.1	3.1
Cu Ro Conc 3	26.6	2.67	2.10	7.25	1.09	21.3	2.2	3.6	18.4	3.8
Cu Ro Conc 4	35.0	3.51	1.80	7.14	0.79	19.2	2.4	4.7	17.5	4.5
Zn Ro Conc	104.2	10.45	11.6	21.4	0.15	20.9	46.6	41.6	9.9	14.7
Tail	797.4	79.97	1.49	3.05	0.05	13.3	45.8	45.3	25.3	71.4
Head (calc.)	997.1	100.00	2.60	5.38	0.16	14.9	100.0	100.0	100.0	100.0

Calculated Balance

Cu Ro Conc 1	15.1	1.51	2.39	7.82	1.34	24.0	1.4	2.2	12.8	2.4
Cu Ro Conc 1-2	33.9	3.40	2.37	7.65	1.35	24.3	3.1	4.8	28.9	5.6
Cu Ro Conc 1-4	95.5	9.58	2.09	7.35	1.07	21.6	7.7	13.1	64.8	13.9

Sept. 1/92 Test: 12

Pulp Potential: -100
(mV vs Ag/AgCl)
Flotation Gas: Nitrogen

Stage	Reagents (g/t)						Time (min)		
	CaO	3418	MIBC	CuSO4	SEX	SO2	Grind	Cond	Froth
Grind	-	-	-				43		
Aeration									
Rougher-1	-	-	10	-	-	-		-	0.5
Rougher-2	-	-	-	-	-	-		-	0.5
Rougher-3	-	-	-	-	-	-		-	1
Rougher 4	-	-	-	-	-	-		-	2
Condition	y	-	-	-	-	-			
Condition	-	-	-	415	-	-		1	
Rougher	-	-	-	-	60	-			1

Metallurgical Balance

Product	Weight		Grade,%				% Recovery			
	g	%	Cu	Zn	Pb	Fe	Cu	Zn	Pb	Fe
Cu Ro Conc 1	25.9	2.70	13.9	8.81	0.78	27.4	14.1	4.1	14.9	4.9
Cu Ro Conc 2	39.1	4.08	11.6	8.94	0.70	26.6	17.8	6.3	20.2	7.2
Cu Ro Conc 3	34.8	3.63	7.71	8.87	0.60	24.6	10.5	5.6	15.4	5.9
Cu Ro Conc 4	34.8	3.63	3.01	7.88	0.52	20.4	4.1	5.0	13.4	4.9
Zn Ro Conc	133.2	13.91	6.31	24.2	0.16	23.1	32.9	58.4	15.7	21.4
Tail	689.7	72.03	0.76	1.65	0.04	11.6	20.5	20.6	20.4	55.6
Head (calc.)	957.5	100.00	2.66	5.77	0.14	15.0	100.0	100.0	100.0	100.0

Calculated Balance

Cu Ro Conc 1	25.9	2.70	13.9	8.81	0.78	27.4	14.1	4.1	14.9	4.9
Cu Ro Conc 1-2	65.0	6.79	12.5	8.89	0.73	26.9	31.9	10.5	35.1	12.2
Cu Ro Conc 1-4	134.6	14.06	8.82	8.62	0.64	24.6	46.5	21.0	63.9	23.0

Sept. 1/92 Test: 13

Pulp Potential: -50
(mV vs Ag/AgCl)
Flotation Gas: Air

Stage	Reagents (g/t)						Time (min)		
	CaO	3418	MIBC	CuSO4	SEX	SO2	Grind	Cond	Froth
Grind	-	-	-				43		
Aeration									
Rougher-1	-	-	10	-	-	-		-	0.5
Rougher-2	-	-	-	-	-	-		-	0.5
Rougher-3	-	-	-	-	-	-		-	1
Rougher 4	-	-	-	-	-	-		-	2
Condition	y	-	-	-	-	-			
Condition	-	-	-	415	-	-		1	
Rougher	-	-	-	-	60	-			1

Metallurgical Balance

Product	Weight		Grade,%				% Recovery			
	g	%	Cu	Zn	Pb	Fe	Cu	Zn	Pb	Fe
Cu Ro Conc 1	29.4	3.04	14.5	8.64	0.76	27.0	16.3	4.6	17.5	5.4
Cu Ro Conc 2	32.2	3.33	15.1	10.5	0.62	27.5	18.6	6.1	15.6	6.0
Cu Ro Conc 3	39.3	4.07	12.4	11.9	0.48	26.2	18.7	8.5	14.7	7.0
Cu Ro Conc 4	62.9	6.51	7.28	14.1	0.35	23.7	17.5	16.0	17.2	10.1
Zn Ro Conc	85.0	8.80	2.87	30.4	0.19	21.0	9.3	46.7	12.6	12.1
Tail	717.0	74.24	0.71	1.39	0.04	12.3	19.5	18.0	22.4	59.6
Head (calc.)	965.8	100.00	2.70	5.72	0.13	15.3	100.0	100.0	100.0	100.0

Calculated Balance

Cu Ro Conc 1	29.4	3.04	14.5	8.64	0.76	27.0	16.3	4.6	17.5	5.4
Cu Ro Conc 1-2	61.6	6.38	14.8	9.61	0.69	27.3	35.0	10.7	33.0	11.3
Cu Ro Conc 1-4	163.8	16.96	11.3	11.88	0.51	25.6	71.2	35.2	65.0	28.4

Sept. 1/92 Test: 15

Pulp Potential: -50
(mV vs Ag/AgCl)
Flotation Gas: Nitrogen

Stage	Reagents (g/t)						Time (min)		
	CaO	3418	MIBC	CuSO4	SEX	SO2	Grind	Cond	Froth
Grind	-	-	-				43		
Aeration									
Rougher-1	-	-	10	-	-	-		-	0.5
Rougher-2	-	-	-	-	-	-		-	0.5
Rougher-3	-	-	-	-	-	-		-	1
Rougher 4	-	-	-	-	-	-		-	2
Condition	y	-	-	-	-	-			
Condition	-	-	-	415	-	-		1	
Rougher	-	-	-	-	60	-			1

Metallurgical Balance

Product	Weight		Grade,%				% Recovery			
	g	%	Cu	Zn	Pb	Fe	Cu	Zn	Pb	Fe
Cu Ro Conc 1	40.9	4.21	12.9	8.49	0.63	27.9	20.4	6.3	17.9	7.7
Cu Ro Conc 2	30.0	3.08	12.0	9.46	0.74	27.1	13.9	5.2	15.4	5.4
Cu Ro Conc 3	40.6	4.17	6.7	9.07	0.70	23.4	10.5	6.7	19.7	6.4
Cu Ro Conc 4	39.0	4.01	2.37	7.85	0.58	19.2	3.6	5.6	15.7	5.0
Zn Ro Conc	94.4	9.70	5.99	28.8	0.17	20.6	21.8	49.5	11.1	13.0
Tail	728.2	74.83	1.06	2.02	0.04	12.8	29.8	26.8	20.2	62.5
Head (calc.)	973.0	100.00	2.66	5.65	0.15	15.3	100.0	100.0	100.0	100.0

Calculated Balance

Cu Ro Conc 1	40.9	4.21	12.9	8.49	0.63	27.9	20.4	6.3	17.9	7.7
Cu Ro Conc 1-2	70.9	7.28	12.5	8.90	0.68	27.6	34.3	11.5	33.3	13.1
Cu Ro Conc 1-4	150.5	15.47	8.31	8.67	0.66	24.3	48.3	23.8	68.7	24.5

Sept. 1/92 Test: 16

Pulp Potential: -220
(mV vs Ag/AgCl)
Flotation Gas: Air

Stage	Reagents (g/t)						Time (min)		
	CaO	3418	MIBC	CuSO4	SEX	SO2	Grind	Cond	Froth
Grind	-	-	-				43		
Aeration									
Rougher-1	-	-	10	-	-	-		-	0.5
Rougher-2	-	-	-	-	-	-		-	0.5
Rougher-3	-	-	-	-	-	-		-	1
Rougher 4	-	-	-	-	-	-		-	2
Condition	y	-	-	-	-	-			
Condition	-	-	-	415	-	-		1	
Rougher	-	-	-	-	60	-			1

Metallurgical Balance

Product	Weight		Grade,%				% Recovery			
	g	%	Cu	Zn	Pb	Fe	Cu	Zn	Pb	Fe
Cu Ro Conc 1	26.8	2.79	3.51	8.94	1.31	23.5	3.9	4.4	23.2	4.4
Cu Ro Conc 2	37.2	3.87	6.87	9.69	0.89	22.8	10.5	6.7	21.9	5.9
Cu Ro Conc 3	37.5	3.90	8.35	10.1	0.59	22.5	12.8	7.0	14.6	5.8
Cu Ro Conc 4	47.7	4.96	7.84	10.0	0.36	21.6	15.3	8.8	11.3	7.1
Zn Ro Conc	89.3	9.28	5.88	31.0	0.17	19.1	21.5	51.1	10.0	11.8
Tail	723.0	75.19	1.22	1.65	0.04	13.0	36.1	22.0	19.1	65.0
Head (calc.)	961.4	100.00	2.54	5.63	0.16	15.0	100.0	100.0	100.0	100.0

Calculated Balance

Cu Ro Conc 1	26.8	2.79	3.51	8.94	1.31	23.5	3.9	4.4	23.2	4.4
Cu Ro Conc 1-2	64.0	6.66	5.46	9.38	1.07	23.1	14.3	11.1	45.0	10.2
Cu Ro Conc 1-4	149.2	15.52	6.95	9.76	0.72	22.5	42.4	26.9	70.9	23.2

Sept. 3/92 Test: 17

Pulp Potential: 25
(mV vs Ag/AgCl)
Flotation Gas: Air

Stage	Reagents (g/t)						Time (min)		
	CaO	3418	MIBC	CuSO4	SEX	SO2	Grind	Cond	Froth
Grind	-	-	-				43		
Aeration									
Rougher-1	-	-	10	-	-	-		-	0.5
Rougher-2	-	-	-	-	-	-		-	0.5
Rougher-3	-	-	-	-	-	-		-	1
Rougher 4	-	-	-	-	-	-		-	2
Condition	y	-	-	-	-	-			
Condition	-	-	-	415	-	-		1	
Rougher	-	-	-	-	60	-			1

Metallurgical Balance

Product	Weight		Grade,%				% Recovery			
	g	%	Cu	Zn	Pb	Fe	Cu	Zn	Pb	Fe
Cu Ro Conc 1	68.0	6.94	14.9	10.8	0.58	27.1	37.5	13.0	30.9	12.3
Cu Ro Conc 2	36.0	3.68	12.1	13.1	0.49	26.2	16.2	8.4	13.8	6.3
Cu Ro Conc 3	40.3	4.12	8.62	14.9	0.41	24.4	12.9	10.7	13.0	6.6
Cu Ro Conc 4	42.8	4.37	5.19	16.7	0.34	22.4	8.2	12.7	11.4	6.4
Zn Ro Conc	91.8	9.37	2.75	24.3	0.20	24.5	9.4	39.6	14.4	15.0
Tail	701.0	71.53	0.61	1.25	0.03	11.4	15.8	15.6	16.5	53.4
Head (calc.)	979.9	100.00	2.75	5.74	0.13	15.3	100.0	100.0	100.0	100.0

Calculated Balance

Cu Ro Conc 1	68.0	6.94	14.9	10.8	0.58	27.1	37.5	13.0	30.9	12.3
Cu Ro Conc 1-2	104.0	10.61	13.9	11.6	0.55	26.8	53.7	21.4	44.7	18.6
Cu Ro Conc 1-4	187.2	19.10	10.8	13.5	0.47	25.3	74.8	44.8	69.1	31.6

Nov 29/92 Test: 22

Pulp Potential: 25
(mV vs Ag/AgCl)
Flotation Gas: Air

Stage	Reagents (g/t)						Time (min)		
	CaO	3418	MIBC	CuSO4	SEX	SO2	Grind	Cond	Froth
Grind	-	-	-				43		
Aeration									
Rougher-1	-	-	10	-	-	-		-	0.5
Rougher-2	-	-	-	-	-	-		-	0.5
Rougher-3	-	-	-	-	-	-		-	1
Rougher 4	-	-	-	-	-	-		-	2
Condition	y	-	-	-	-	-			
Condition	-	-	-	415	-	-		1	
Rougher	-	-	-	-	60	-			1

Metallurgical Balance

Product	Weight		Grade,%				% Recovery			
	g	%	Cu	Zn	Pb	Fe	Cu	Zn	Pb	Fe
Cu Ro Conc 1	53.8	5.65	10.5	7.48	0.61	24.4	27.0	8.1	24.9	10.3
Cu Ro Conc 2	33.7	3.54	9.67	12.0	0.57	22.4	15.6	8.2	14.6	5.9
Cu Ro Conc 3	43.7	4.58	6.84	11.0	0.28	20.0	14.3	9.7	9.3	6.9
Cu Ro Conc 4	46.5	4.88	3.98	12.4	0.36	19.0	8.9	11.6	12.7	7.0
Zn Ro Conc	79.7	8.37	3.40	27.5	0.20	22.5	13.0	44.2	12.1	14.1
Tail	695.2	72.98	0.64	1.30	0.05	10.2	21.3	18.2	26.4	55.8
Head (calc.)	952.7	100.00	2.19	5.21	0.14	13.3	100.0	100.0	100.0	100.0

Calculated Balance

Cu Ro Conc 1	53.8	5.65	10.5	7.48	0.61	24.4	27.0	8.1	24.9	10.3
Cu Ro Conc 1-2	87.5	9.19	10.2	9.22	0.59	23.6	42.6	16.3	39.5	16.3
Cu Ro Conc 1-4	177.7	18.65	7.74	10.5	0.46	21.5	65.8	37.6	61.5	30.1

Dec 3/92 Test: 22b

Pulp Potential: 25
(mV vs Ag/AgCl)
Flotation Gas: Air

Stage	Reagents (g/t)						Time (min)		
	CaO	3418	MIBC	CuSO4	SEX	SO2	Grind	Cond	Froth
Grind	-	-	-				43		
Aeration									
Rougher-1	-	-	10	-	-	-		-	0.5
Rougher-2	-	-	-	-	-	-		-	0.5
Rougher-3	-	-	-	-	-	-		-	1
Rougher 4	-	-	-	-	-	-		-	2
Condition	y	-	-	-	-	-			
Condition	-	-	-	415	-	-		1	
Rougher	-	-	-	-	60	-			1

Metallurgical Balance

Product	Weight		Grade,%				% Recovery			
	g	%	Cu	Zn	Pb	Fe	Cu	Zn	Pb	Fe
Cu Ro Conc 1	55.9	5.83	10.8	7.80	0.70	25.0	27.7	8.4	30.3	10.4
Cu Ro Conc 2	31.8	3.32	9.98	12.4	0.66	23.8	14.6	7.6	16.2	5.6
Cu Ro Conc 3	41.8	4.36	6.61	12.8	0.30	21.1	12.7	10.4	9.7	6.6
Cu Ro Conc 4	46.2	4.82	4.13	13.0	0.28	18.8	8.8	11.6	10.0	6.5
Zn Ro Conc	82.3	8.59	3.20	26.9	0.19	22.2	12.1	42.8	12.1	13.6
Tail	700.5	73.08	0.75	1.42	0.04	11.0	24.1	19.2	21.7	57.3
Head (calc.)	958.5	100.00	2.27	5.40	0.13	14.0	100.0	100.0	100.0	100.0

Calculated Balance

Cu Ro Conc 1	55.9	5.83	10.8	7.80	0.70	25.0	27.7	8.4	30.3	10.4
Cu Ro Conc 1-2	87.7	9.15	10.5	9.47	0.69	24.6	42.3	16.1	46.5	16.0
Cu Ro Conc 1-4	175.7	18.33	7.89	11.2	0.49	22.2	63.8	38.0	66.2	29.1

Dec 9/92 Test: 22c

Pulp Potential: 25
(mV vs Ag/AgCl)
Flotation Gas: Air

Stage	Reagents (g/t)						Time (min)		
	CaO	3418	MIBC	CuSO4	SEX	SO2	Grind	Cond	Froth
Grind	-	-	-				43		
Aeration									
Rougher-1	-	-	10	-	-	-		-	0.5
Rougher-2	-	-	-	-	-	-		-	0.5
Rougher-3	-	-	-	-	-	-		-	1
Rougher 4	-	-	-	-	-	-		-	2
Condition	y	-	-	-	-	-			
Condition	-	-	-	415	-	-		1	
Rougher	-	-	-	-	60	-			1

Metallurgical Balance

Product	Weight		Grade,%				% Recovery			
	g	%	Cu	Zn	Pb	Fe	Cu	Zn	Pb	Fe
Cu Ro Conc 1	57.9	5.89	11.3	8.02	0.88	25.3	26.6	9.0	33.4	11.3
Cu Ro Conc 2	42.7	4.34	10.3	13.4	0.75	23.5	17.8	11.1	21.0	7.7
Cu Ro Conc 3	46.5	4.73	6.76	14.0	0.54	20.9	12.8	12.5	16.5	7.5
Cu Ro Conc 4	48.3	4.91	3.89	14.1	0.33	19.2	7.6	13.2	10.5	7.1
Zn Ro Conc	78.0	7.93	2.87	25.3	0.09	21.5	9.1	38.1	4.6	12.9
Tail	710.2	72.20	0.90	1.17	0.03	9.80	26.0	16.1	14.0	53.5
Head (calc.)	983.7	100.00	2.50	5.26	0.15	13.2	100.0	100.0	100.0	100.0

Calculated Balance

Cu Ro Conc 1	57.9	5.89	11.3	8.02	0.88	25.3	26.6	9.0	33.4	11.3
Cu Ro Conc 1-2	100.6	10.23	10.9	10.3	0.82	24.5	44.5	20.1	54.5	19.0
Cu Ro Conc 1-4	195.4	19.87	8.17	12.1	0.63	22.4	64.9	45.8	81.4	33.6

Sept. 3/92 Test: 18

Pulp Potential: -100
(mV vs Ag/AgCl)
Flotation Gas: Air

Stage	Reagents (g/t)						Time (min)		
	CaO	3418	MIBC	CuSO4	SEX	SO2	Grind	Cond	Froth
Grind	-	-	-				43		
Aeration									
Rougher-1	-	-	10	-	-	-		-	0.5
Rougher-2	-	-	-	-	-	-		-	0.5
Rougher-3	-	-	-	-	-	-		-	1
Rougher 4	-	-	-	-	-	-		-	2
Condition	y	-	-	-	-	-			
Condition	-	-	-	415	-	-		1	
Rougher	-	-	-	-	60	-			1

Metallurgical Balance

Product	Weight		Grade,%				% Recovery			
	g	%	Cu	Zn	Pb	Fe	Cu	Zn	Pb	Fe
Cu Ro Conc 1	68.7	7.12	13.8	10.1	0.68	27.1	36.4	12.3	32.9	12.7
Cu Ro Conc 2	29.7	3.08	11.1	12.1	0.52	25.9	12.7	6.4	10.9	5.2
Cu Ro Conc 3	49.2	5.10	6.89	13.3	0.40	22.5	13.0	11.6	13.9	7.5
Cu Ro Conc 4	48.4	5.01	4.07	14.6	0.33	20.0	7.6	12.6	11.3	6.6
Zn Ro Conc	88.4	9.15	2.84	27.3	0.19	22.1	9.6	42.9	11.8	13.3
Tail	680.9	70.53	0.79	1.17	0.04	11.8	20.7	14.2	19.2	54.7
Head (calc.)	965.4	100.00	2.70	5.83	0.15	15.2	100.0	100.0	100.0	100.0

Calculated Balance

Cu Ro Conc 1	68.7	7.12	13.8	10.1	0.68	27.1	36.4	12.3	32.9	12.7
Cu Ro Conc 1-2	98.5	10.20	13.0	10.7	0.63	26.7	49.1	18.7	43.8	17.9
Cu Ro Conc 1-4	196.1	20.31	9.25	12.3	0.50	24.0	69.7	42.9	69.0	32.0

Nov 29/92 Test: 19

Pulp Potential: -25
(mV vs Ag/AgCl)
Flotation Gas: Air

Stage	Reagents (g/t)						Time (min)		
	CaO	3418	MIBC	CuSO4	SEX	SO2	Grind	Cond	Froth
Grind	-	-	-				43		
Aeration									
Rougher-1	-	-	10	-	-	-		-	0.5
Rougher-2	-	-	-	-	-	-		-	0.5
Rougher-3	-	-	-	-	-	-		-	1
Rougher 4	-	-	-	-	-	-		-	2
Condition	y	-	-	-	-	-			
Condition	-	-	-	415	-	-		1	
Rougher	-	-	-	-	60	-			1

Metallurgical Balance

Product	Weight		Grade,%				% Recovery			
	g	%	Cu	Zn	Pb	Fe	Cu	Zn	Pb	Fe
Cu Ro Conc 1	43.4	4.57	12.0	9.76	0.76	25.3	22.6	8.2	24.3	8.4
Cu Ro Conc 2	36.9	3.88	10.8	10.7	0.57	23.9	17.3	7.6	15.5	6.8
Cu Ro Conc 3	39.8	4.20	8.11	8.04	0.31	20.6	14.0	6.2	9.1	6.3
Cu Ro Conc 4	50.5	5.33	4.39	11.8	0.36	19.4	9.6	11.5	13.4	7.5
Zn Ro Conc	88.5	9.33	3.54	28.4	0.19	22.0	13.6	48.6	12.4	14.9
Tail	689.7	72.69	0.76	1.34	0.05	10.6	22.8	17.9	25.4	56.1
Head (calc.)	948.9	100.00	2.43	5.45	0.14	13.7	100.0	100.0	100.0	100.0

Calculated Balance

Cu Ro Conc 1	43.4	4.57	12.0	9.76	0.76	25.3	22.6	8.2	24.3	8.4
Cu Ro Conc 1-2	80.3	8.46	11.4	10.2	0.67	24.7	39.9	15.8	39.7	15.2
Cu Ro Conc 1-4	170.6	17.98	8.58	10.2	0.50	22.2	63.6	33.5	62.2	29.0

Nov 29/92 Test: 20

Pulp Potential: -150
(mV vs Ag/AgCl)
Flotation Gas: Air

Stage	Reagents (g/t)						Time (min)		
	CaO	3418	MIBC	CuSO4	SEX	SO2	Grind	Cond	Froth
Grind	-	-	-				43		
Aeration									
Rougher-1	-	-	10	-	-	-		-	0.5
Rougher-2	-	-	-	-	-	-		-	0.5
Rougher-3	-	-	-	-	-	-		-	1
Rougher 4	-	-	-	-	-	-		-	2
Condition	y	-	-	-	-	-			
Condition	-	-	-	415	-	-		1	
Rougher	-	-	-	-	60	-			1

Metallurgical Balance

Product	Weight		Grade,%				% Recovery			
	g	%	Cu	Zn	Pb	Fe	Cu	Zn	Pb	Fe
Cu Ro Conc 1	36.7	3.77	8.7	7.45	0.43	25.4	15.6	5.4	13.3	7.4
Cu Ro Conc 2	25.6	2.62	9.2	7.95	0.68	23.5	11.4	4.0	14.7	4.8
Cu Ro Conc 3	45.4	4.66	7.98	10.9	0.29	20.5	17.7	9.8	11.1	7.4
Cu Ro Conc 4	52.1	5.34	5.90	9.95	0.40	20.3	15.0	10.3	17.6	8.4
Zn Ro Conc	76.8	7.88	3.45	30.1	0.19	20.7	12.9	45.8	12.3	12.6
Tail	738.1	75.73	0.76	1.69	0.05	10.2	27.4	24.7	31.1	59.6
Head (calc.)	974.6	100.00	2.10	5.18	0.12	13.0	100.0	100.0	100.0	100.0

Calculated Balance

Cu Ro Conc 1	36.7	3.77	8.67	7.45	0.43	25.4	15.6	5.4	13.3	7.4
Cu Ro Conc 1-2	62.3	6.39	8.87	7.66	0.53	24.6	27.0	9.4	28.0	12.1
Cu Ro Conc 1-4	159.8	16.39	7.65	9.32	0.42	22.0	59.7	29.5	56.6	27.9

Nov 29/92 Test: 21

Pulp Potential: 0
(mV vs Ag/AgCl)
Flotation Gas: Air

Stage	Reagents (g/t)						Time (min)		
	CaO	3418	MIBC	CuSO4	SEX	SO2	Grind	Cond	Froth
Grind	-	-	-				43		
Aeration									
Rougher-1	-	-	10	-	-	-		-	0.5
Rougher-2	-	-	-	-	-	-		-	0.5
Rougher-3	-	-	-	-	-	-		-	1
Rougher 4	-	-	-	-	-	-		-	2
Condition	y	-	-	-	-	-			
Condition	-	-	-	415	-	-		1	
Rougher	-	-	-	-	60	-			1

Metallurgical Balance

Product	Weight		Grade,%				% Recovery			
	g	%	Cu	Zn	Pb	Fe	Cu	Zn	Pb	Fe
Cu Ro Conc 1	53.2	5.21	11.1	8.89	0.69	24.8	24.4	8.3	25.9	9.7
Cu Ro Conc 2	33.4	3.27	9.79	10.0	0.59	23.2	13.5	5.9	13.9	5.7
Cu Ro Conc 3	54.5	5.33	6.60	9.48	0.25	19.6	14.9	9.1	9.6	7.8
Cu Ro Conc 4	46.8	4.58	4.06	11.6	0.36	19.4	7.9	9.5	11.9	6.6
Zn Ro Conc	93.0	9.10	4.63	28.0	0.19	21.2	17.8	45.8	12.5	14.4
Tail	740.9	72.52	0.70	1.64	0.05	10.3	21.5	21.4	26.2	55.8
Head (calc.)	1021.7	100.00	2.36	5.56	0.14	13.4	100.0	100.0	100.0	100.0

Calculated Balance

Cu Ro Conc 1	53.2	5.21	11.1	8.89	0.69	24.8	24.4	8.3	25.9	9.7
Cu Ro Conc 1-2	86.6	8.48	10.6	9.32	0.65	24.2	38.0	14.2	39.9	15.3
Cu Ro Conc 1-4	187.8	18.38	7.81	9.93	0.46	21.7	60.7	32.8	61.4	29.8

Dec 3/92 Test: 24

Pulp Potential: -100
(mV vs Ag/AgCl)
Flotation Gas: Air

Stage	Reagents (g/t)						Time (min)		
	CaO	3418	MIBC	CuSO4	SEX	SO2	Grind	Cond	Froth
Grind	-	-	-				43		
Aeration									
Rougher-1	-	-	10	-	-	450		-	0.5
Rougher-2	-	-	-	-	-	-		-	0.5
Rougher-3	-	-	-	-	-	-		-	1
Rougher 4	-	-	-	-	-	-		-	2
Condition	y	-	-	-	-	-			
Condition	-	-	-	415	-	-		1	
Rougher	-	-	-	-	60	-			1

Metallurgical Balance

Product	Weight		Grade,%				% Recovery			
	g	%	Cu	Zn	Pb	Fe	Cu	Zn	Pb	Fe
Cu Ro Conc 1	35.2	3.84	8.84	7.16	0.37	23.6	15.5	5.3	11.0	7.1
Cu Ro Conc 2	32.4	3.53	8.31	7.38	0.61	20.6	13.4	5.0	16.7	5.7
Cu Ro Conc 3	34.8	3.79	7.25	6.76	0.27	19.3	12.6	5.0	7.9	5.7
Cu Ro Conc 4	49.1	5.35	4.47	7.99	0.40	18.1	10.9	8.3	16.6	7.5
Zn Ro Conc	75.7	8.25	5.26	33.4	0.20	17.6	19.8	53.3	12.8	11.3
Tail	690.6	75.24	0.81	1.59	0.06	10.7	27.8	23.1	35.0	62.7
Head (calc.)	917.8	100.00	2.19	5.17	0.13	12.8	100.0	100.0	100.0	100.0

Calculated Balance

Cu Ro Conc 1	35.2	3.84	8.84	7.16	0.37	23.6	15.5	5.3	11.0	7.1
Cu Ro Conc 1-2	67.6	7.37	8.59	7.27	0.49	22.2	28.9	10.4	27.7	12.7
Cu Ro Conc 1-4	151.5	16.51	6.95	7.38	0.41	20.2	52.4	23.6	52.2	26.0

Dec 3/92 Test: 25

Pulp Potential: 0
(mV vs Ag/AgCl)
Flotation Gas: Air

Stage	Reagents (g/t)						Time (min)		
	CaO	3418	MIBC	CuSO4	SEX	SO2	Grind	Cond	Froth
Grind	-	-	-				43		
Aeration									
Rougher-1	-	-	10	-	-	450		-	0.5
Rougher-2	-	-	-	-	-	-		-	0.5
Rougher-3	-	-	-	-	-	-		-	1
Rougher 4	-	-	-	-	-	-		-	2
Condition	y	-	-	-	-	-			
Condition	-	-	-	415	-	-		1	
Rougher	-	-	-	-	60	-			1

Metallurgical Balance

Product	Weight		Grade,%				% Recovery			
	g	%	Cu	Zn	Pb	Fe	Cu	Zn	Pb	Fe
Cu Ro Conc 1	42.8	4.65	11.4	7.43	0.56	25.0	22.7	6.3	19.2	8.9
Cu Ro Conc 2	38.1	4.13	9.94	8.08	0.49	22.6	17.6	6.1	14.9	7.2
Cu Ro Conc 3	35.3	3.83	8.27	8.32	0.27	20.8	13.6	5.8	7.6	6.1
Cu Ro Conc 4	43.2	4.69	4.72	9.96	0.40	19.6	9.5	8.6	13.8	7.0
Zn Ro Conc	66.7	7.25	3.88	38.2	0.21	15.2	12.0	50.7	11.2	8.4
Tail	694.6	75.44	0.76	1.62	0.06	10.8	24.6	22.4	33.3	62.4
Head (calc.)	920.7	100.00	2.33	5.46	0.14	13.1	100.0	100.0	100.0	100.0

Calculated Balance

Cu Ro Conc 1	42.8	4.65	11.4	7.43	0.56	25.0	22.7	6.3	19.2	8.9
Cu Ro Conc 1-2	80.9	8.79	10.7	7.74	0.53	23.9	40.3	12.5	34.1	16.1
Cu Ro Conc 1-4	159.4	17.31	8.55	8.47	0.44	22.0	63.4	26.9	55.5	29.2

Dec 3/92 Test: 26

Pulp Potential: -220
(mV vs Ag/AgCl)
Flotation Gas: Air

Stage	Reagents (g/t)						Time (min)		
	CaO	3418	MIBC	CuSO4	SEX	SO2	Grind	Cond	Froth
Grind	-	-	-				43		
Aeration									
Rougher-1	-	-	10	-	-	450		-	0.5
Rougher-2	-	-	-	-	-	-		-	0.5
Rougher-3	-	-	-	-	-	-		-	1
Rougher 4	-	-	-	-	-	-		-	2
Condition	y	-	-	-	-	-			
Condition	-	-	-	415	-	-		1	
Rougher	-	-	-	-	60	-			1

Metallurgical Balance

Product	Weight		Grade,%				% Recovery			
	g	%	Cu	Zn	Pb	Fe	Cu	Zn	Pb	Fe
Cu Ro Conc 1	20.5	2.12	3.52	7.22	0.74	22.1	3.5	3.0	11.0	3.8
Cu Ro Conc 2	22.7	2.35	6.34	7.60	0.76	21.3	7.0	3.5	12.5	4.1
Cu Ro Conc 3	39.2	4.07	7.04	6.94	0.34	19.5	13.5	5.6	9.7	6.5
Cu Ro Conc 4	55.4	5.75	5.74	8.36	0.46	19.4	15.6	9.5	18.5	9.1
Zn Ro Conc	70.8	7.34	6.93	34.1	0.19	15.7	24.0	49.4	9.8	9.4
Tail	755.5	78.37	0.98	1.87	0.07	10.5	36.3	28.9	38.5	67.1
Head (calc.)	964.1	100.00	2.12	5.06	0.14	12.3	100.0	100.0	100.0	100.0

Calculated Balance

Cu Ro Conc 1	20.5	2.12	3.52	7.22	0.74	22.1	3.5	3.0	11.0	3.8
Cu Ro Conc 1-2	43.1	4.47	5.00	7.42	0.75	21.7	10.6	6.6	23.5	7.9
Cu Ro Conc 1-4	137.8	14.29	5.88	7.66	0.52	20.1	39.7	21.6	51.8	23.5

Dec 3/92 Test: 27

Pulp Potential: -150
(mV vs Ag/AgCl)
Flotation Gas: Air

Stage	Reagents (g/t)						Time (min)		
	CaO	3418	MIBC	CuSO4	SEX	SO2	Grind	Cond	Froth
Grind	-	-	-				43		
Aeration									
Rougher-1	-	-	10	-	-	450		-	0.5
Rougher-2	-	-	-	-	-	-		-	0.5
Rougher-3	-	-	-	-	-	-		-	1
Rougher 4	-	-	-	-	-	-		-	2
Condition	y	-	-	-	-	-			
Condition	-	-	-	415	-	-		1	
Rougher	-	-	-	-	60	-			1

Metallurgical Balance

Product	Weight		Grade,%				% Recovery			
	g	%	Cu	Zn	Pb	Fe	Cu	Zn	Pb	Fe
Cu Ro Conc 1	30.7	3.25	5.85	7.80	0.36	24.0	8.5	4.7	9.0	6.1
Cu Ro Conc 2	26.2	2.78	7.78	7.58	0.66	21.9	9.7	3.9	14.1	4.8
Cu Ro Conc 3	48.3	5.12	7.69	7.07	0.30	20.2	17.7	6.7	11.8	8.1
Cu Ro Conc 4	57.4	6.08	5.24	8.45	0.42	18.8	14.3	9.5	19.6	8.9
Zn Ro Conc	76.9	8.15	5.68	35.9	0.18	15.4	20.7	54.0	11.2	9.8
Tail	703.7	74.61	0.87	1.54	0.06	10.7	29.1	21.2	34.3	62.3
Head (calc.)	943.2	100.00	2.23	5.42	0.13	12.8	100.0	100.0	100.0	100.0

Calculated Balance

Cu Ro Conc 1	30.7	3.25	5.85	7.80	0.36	24.0	8.5	4.7	9.0	6.1
Cu Ro Conc 1-2	56.9	6.03	6.74	7.70	0.50	23.0	18.2	8.6	23.0	10.8
Cu Ro Conc 1-4	162.6	17.24	6.49	7.78	0.41	20.7	50.2	24.8	54.4	27.9

Dec 4/92 Test: 28

Pulp Potential: -50
(mV vs Ag/AgCl)
Flotation Gas: Air

Stage	Reagents (g/t)						Time (min)		
	CaO	3418	MIBC	CuSO4	SEX	SO2	Grind	Cond	Froth
Grind	-	-	-				43		
Aeration									
Rougher-1	-	-	10	-	-	450		-	0.5
Rougher-2	-	-	-	-	-	-		-	0.5
Rougher-3	-	-	-	-	-	-		-	1
Rougher 4	-	-	-	-	-	-		-	2
Condition	y	-	-	-	-	-			
Condition	-	-	-	415	-	-		1	
Rougher	-	-	-	-	60	-			1

Metallurgical Balance

Product	Weight		Grade,%				% Recovery			
	g	%	Cu	Zn	Pb	Fe	Cu	Zn	Pb	Fe
Cu Ro Conc 1	43.4	4.79	10.2	7.67	0.34	23.5	20.5	6.7	12.8	8.5
Cu Ro Conc 2	30.7	3.40	8.88	7.90	0.53	21.6	12.6	4.9	14.2	5.5
Cu Ro Conc 3	38.6	4.26	7.30	7.61	0.26	19.6	13.0	5.9	8.7	6.3
Cu Ro Conc 4	53.6	5.93	4.16	9.34	0.40	18.0	10.3	10.1	18.7	8.1
Zn Ro Conc	85.6	9.46	4.56	30.5	0.23	20.0	18.1	52.6	17.1	14.3
Tail	652.9	72.16	0.84	1.50	0.05	10.5	25.4	19.7	28.4	57.3
Head (calc.)	904.8	100.00	2.39	5.48	0.13	13.2	100.0	100.0	100.0	100.0

Calculated Balance

Cu Ro Conc 1	43.4	4.79	10.2	7.67	0.34	23.5	20.5	6.7	12.8	8.5
Cu Ro Conc 1-2	74.1	8.19	9.65	7.77	0.42	22.7	33.1	11.6	27.0	14.1
Cu Ro Conc 1-4	166.3	18.38	7.34	8.24	0.38	20.5	56.5	27.6	54.4	28.4

Dec 4/92 Test: 29

Pulp Potential: 25
(mV vs Ag/AgCl)
Flotation Gas: Air

Stage	Reagents (g/t)						Time (min)		
	CaO	3418	MIBC	CuSO4	SEX	SO2	Grind	Cond	Froth
Grind	-	-	-				43		
Aeration									
Rougher-1	-	-	10	-	-	450		-	0.5
Rougher-2	-	-	-	-	-	-		-	0.5
Rougher-3	-	-	-	-	-	-		-	1
Rougher 4	-	-	-	-	-	-		-	2
Condition	y	-	-	-	-	-			
Condition	-	-	-	415	-	-		1	
Rougher	-	-	-	-	60	-			1

Metallurgical Balance

Product	Weight		Grade,%				% Recovery			
	g	%	Cu	Zn	Pb	Fe	Cu	Zn	Pb	Fe
Cu Ro Conc 1	43.8	4.76	13.1	8.88	0.57	25.0	25.4	7.4	19.3	8.7
Cu Ro Conc 2	31.3	3.41	10.8	9.48	0.55	23.6	15.0	5.6	13.3	5.9
Cu Ro Conc 3	34.4	3.74	8.41	9.55	0.30	20.5	12.8	6.2	8.0	5.6
Cu Ro Conc 4	43.2	4.70	4.40	10.7	0.42	19.4	8.4	8.8	14.0	6.6
Zn Ro Conc	114.2	12.43	3.85	26.4	0.23	22.7	19.5	57.3	20.3	20.6
Tail	651.7	70.95	0.66	1.18	0.05	10.2	19.0	14.6	25.2	52.7
Head (calc.)	918.5	100.00	2.46	5.73	0.14	13.7	100.0	100.0	100.0	100.0

Calculated Balance

Cu Ro Conc 1	43.8	4.76	13.1	8.88	0.57	25.0	25.4	7.4	19.3	8.7
Cu Ro Conc 1-2	75.1	8.17	12.1	9.13	0.56	24.4	40.3	13.0	32.6	14.5
Cu Ro Conc 1-4	152.6	16.61	9.11	9.67	0.46	22.1	61.5	28.1	54.5	26.8

Dec 4/92 Test: 30

Pulp Potential: -220
(mV vs Ag/AgCl)
Flotation Gas: Air

Stage	Reagents (g/t)						Time (min)		
	CaO	3418	MIBC	CuSO4	SEX	SO2	Grind	Cond	Froth
Grind	-	-	-				43		
Aeration									
Rougher-1	100	-	10	-	-	450		-	0.5
Rougher-2	-	-	-	-	-	-		-	0.5
Rougher-3	-	-	-	-	-	-		-	1
Rougher 4	-	-	-	-	-	-		-	2
Condition	y	-	-	-	-	-			
Condition	-	-	-	415	-	-		1	
Rougher	-	-	-	-	60	-			1

Metallurgical Balance

Product	Weight		Grade,%				% Recovery			
	g	%	Cu	Zn	Pb	Fe	Cu	Zn	Pb	Fe
Cu Ro Conc 1	21.5	2.28	2.57	6.07	0.84	21.1	2.5	2.6	13.3	3.6
Cu Ro Conc 2	22.8	2.41	4.05	6.20	0.81	19.9	4.1	2.8	13.6	3.6
Cu Ro Conc 3	31.1	3.29	6.42	6.32	0.35	19.9	8.9	3.9	8.0	4.9
Cu Ro Conc 4	42.0	4.44	7.31	7.84	0.49	21.0	13.7	6.5	15.1	7.1
Zn Ro Conc	131.0	13.86	7.83	24.5	0.20	21.8	45.7	62.9	19.3	22.8
Tail	697.0	73.73	0.81	1.57	0.06	10.4	25.2	21.4	30.8	57.9
Head (calc.)	945.4	100.00	2.37	5.40	0.14	13.2	100.0	100.0	100.0	100.0

Calculated Balance

Cu Ro Conc 1	21.5	2.28	2.57	6.07	0.84	21.1	2.5	2.6	13.3	3.6
Cu Ro Conc 1-2	44.3	4.68	3.33	6.14	0.82	20.5	6.6	5.3	26.8	7.2
Cu Ro Conc 1-4	117.4	12.41	5.57	6.79	0.58	20.5	29.1	15.6	50.0	19.3

Dec 4/92 Test: 32

Pulp Potential: 25
(mV vs Ag/AgCl)
Flotation Gas: Air

Stage	Reagents (g/t)						Time (min)		
	CaO	3418	MIBC	CuSO4	SEX	SO2	Grind	Cond	Froth
Grind	-	-	-				43		
Aeration									
Rougher-1	100	-	10	-	-	450		-	0.5
Rougher-2	-	-	-	-	-	-		-	0.5
Rougher-3	-	-	-	-	-	-		-	1
Rougher 4	-	-	-	-	-	-		-	2
Condition	y	-	-	-	-	-			
Condition	-	-	-	415	-	-		1	
Rougher	-	-	-	-	60	-			1

Metallurgical Balance

Product	Weight		Grade,%				% Recovery			
	g	%	Cu	Zn	Pb	Fe	Cu	Zn	Pb	Fe
Cu Ro Conc 1	32.3	3.29	11.9	8.94	0.61	24.2	16.3	5.0	14.7	5.9
Cu Ro Conc 2	35.3	3.59	10.0	9.24	0.55	23.0	15.0	5.7	14.5	6.1
Cu Ro Conc 3	41.3	4.20	8.72	9.20	0.30	20.7	15.3	6.6	9.2	6.4
Cu Ro Conc 4	40.6	4.12	5.79	10.7	0.43	20.8	10.0	7.5	13.0	6.4
Zn Ro Conc	130.2	13.24	4.38	26.6	0.23	22.0	24.2	60.1	22.3	21.6
Tail	703.7	71.55	0.64	1.23	0.05	10.1	19.1	15.0	26.2	53.6
Head (calc.)	983.5	100.00	2.39	5.86	0.14	13.5	100.0	100.0	100.0	100.0

Calculated Balance

Cu Ro Conc 1	32.3	3.29	11.9	8.94	0.61	24.2	16.3	5.0	14.7	5.9
Cu Ro Conc 1-2	67.7	6.88	10.9	9.10	0.58	23.6	31.4	10.7	29.2	12.0
Cu Ro Conc 1-4	149.6	15.21	8.92	9.56	0.46	22.0	56.6	24.8	51.4	24.8

Dec 4/92 Test: 33

Pulp Potential: -150
(mV vs Ag/AgCl)
Flotation Gas: Air

Stage	Reagents (g/t)						Time (min)		
	CaO	3418	MIBC	CuSO4	SEX	SO2	Grind	Cond	Froth
Grind	-	-	-				43		
Aeration									
Rougher-1	100	-	10	-	-	450		-	0.5
Rougher-2	-	-	-	-	-	-		-	0.5
Rougher-3	-	-	-	-	-	-		-	1
Rougher 4	-	-	-	-	-	-		-	2
Condition	y	-	-	-	-	-			
Condition	-	-	-	415	-	-		1	
Rougher	-	-	-	-	60	-			1

Metallurgical Balance

Product	Weight		Grade,%				% Recovery			
	g	%	Cu	Zn	Pb	Fe	Cu	Zn	Pb	Fe
Cu Ro Conc 1	25.1	2.62	6.82	6.72	0.40	24.8	7.4	3.1	7.5	4.9
Cu Ro Conc 2	36.4	3.81	8.25	7.02	0.67	23.3	13.0	4.7	18.4	6.7
Cu Ro Conc 3	40.7	4.26	7.88	7.06	0.31	20.6	13.8	5.3	9.5	6.6
Cu Ro Conc 4	53.4	5.59	5.76	9.06	0.40	19.6	13.3	8.9	16.1	8.2
Zn Ro Conc	109.6	11.48	6.53	29.2	0.21	18.8	30.9	59.2	17.3	16.2
Tail	689.8	72.24	0.73	1.47	0.06	10.6	21.7	18.7	31.2	57.5
Head (calc.)	954.9	100.00	2.43	5.66	0.14	13.3	100.0	100.0	100.0	100.0

Calculated Balance

Cu Ro Conc 1	25.1	2.62	6.82	6.72	0.40	24.8	7.4	3.1	7.5	4.9
Cu Ro Conc 1-2	61.5	6.44	7.67	6.90	0.56	23.9	20.3	7.8	25.9	11.6
Cu Ro Conc 1-4	155.5	16.29	7.07	7.68	0.44	21.6	47.4	22.1	51.5	26.4

Dec 4/92 Test: 34

Pulp Potential: -25
(mV vs Ag/AgCl)
Flotation Gas: Air

Stage	Reagents (g/t)						Time (min)		
	CaO	3418	MIBC	CuSO4	SEX	SO2	Grind	Cond	Froth
Grind	-	-	-				43		
Aeration									
Rougher-1	100	-	10	-	-	450		-	0.5
Rougher-2	-	-	-	-	-	-		-	0.5
Rougher-3	-	-	-	-	-	-		-	1
Rougher 4	-	-	-	-	-	-		-	2
Condition	y	-	-	-	-	-			
Condition	-	-	-	415	-	-		1	
Rougher	-	-	-	-	60	-			1

Metallurgical Balance

Product	Weight		Grade,%				% Recovery			
	g	%	Cu	Zn	Pb	Fe	Cu	Zn	Pb	Fe
Cu Ro Conc 1	36.9	4.08	10.5	7.42	0.57	24.5	17.9	5.4	16.9	7.4
Cu Ro Conc 2	30.0	3.32	10.6	8.28	0.52	23.3	14.7	4.9	12.5	5.8
Cu Ro Conc 3	43.3	4.79	7.88	7.06	0.31	20.6	15.7	6.0	10.8	7.3
Cu Ro Conc 4	47.5	5.25	5.76	9.06	0.40	19.6	12.6	8.5	15.3	7.7
Zn Ro Conc	90.4	10.01	4.29	32.5	0.25	19.4	17.9	58.1	18.2	14.5
Tail	655.3	72.55	0.70	1.32	0.05	10.6	21.2	17.1	26.3	57.3
Head (calc.)	903.3	100.00	2.40	5.60	0.14	13.4	100.0	100.0	100.0	100.0

Calculated Balance

Cu Ro Conc 1	36.9	4.08	10.5	7.42	0.57	24.5	17.9	5.4	16.9	7.4
Cu Ro Conc 1-2	66.9	7.40	10.5	7.81	0.55	24.0	32.6	10.3	29.4	13.2
Cu Ro Conc 1-4	157.6	17.44	8.37	7.98	0.44	21.7	60.9	24.8	55.5	28.2

Dec 5/92 Test: 35

Pulp Potential: -100
(mV vs Ag/AgCl)
Flotation Gas: Air

Stage	Reagents (g/t)						Time (min)		
	CaO	3418	MIBC	CuSO4	SEX	SO2	Grind	Cond	Froth
Grind	-	-	-				43		
Aeration									
Rougher-1	100	-	10	-	-	450		-	0.5
Rougher-2	-	-	-	-	-	-		-	0.5
Rougher-3	-	-	-	-	-	-		-	1
Rougher 4	-	-	-	-	-	-		-	2
Condition	y	-	-	-	-	-			
Condition	-	-	-	415	-	-		1	
Rougher	-	-	-	-	60	-			1

Metallurgical Balance

Product	Weight		Grade,%				% Recovery			
	g	%	Cu	Zn	Pb	Fe	Cu	Zn	Pb	Fe
Cu Ro Conc 1	36.1	3.83	8.35	6.85	0.35	24.0	13.8	4.9	10.7	7.0
Cu Ro Conc 2	24.7	2.61	8.86	7.39	0.64	22.8	10.0	3.6	13.4	4.6
Cu Ro Conc 3	42.3	4.48	8.40	7.35	0.31	20.9	16.3	6.1	11.1	7.2
Cu Ro Conc 4	43.1	4.56	5.57	9.12	0.41	19.9	11.0	7.7	15.0	6.9
Zn Ro Conc	78.0	8.26	6.60	34.2	0.20	16.2	23.6	52.4	13.2	10.2
Tail	720.1	76.26	0.77	1.79	0.06	11.0	25.4	25.3	36.6	64.1
Head (calc.)	944.3	100.00	2.31	5.39	0.12	13.1	100.0	100.0	100.0	100.0

Calculated Balance

Cu Ro Conc 1	36.1	3.83	8.35	6.85	0.35	24.0	13.8	4.9	10.7	7.0
Cu Ro Conc 1-2	60.8	6.44	8.56	7.07	0.47	23.5	23.8	8.4	24.1	11.6
Cu Ro Conc 1-4	146.2	15.48	7.63	7.75	0.41	21.7	51.1	22.3	50.2	25.7

Dec 5/92 Test: 36

Pulp Potential: 0
(mV vs Ag/AgCl)
Flotation Gas: Air

Stage	Reagents (g/t)						Time (min)		
	CaO	3418	MIBC	CuSO4	SEX	SO2	Grind	Cond	Froth
Grind	-	-	-				43		
Aeration									
Rougher-1	100	-	10	-	-	450		-	0.5
Rougher-2	-	-	-	-	-	-		-	0.5
Rougher-3	-	-	-	-	-	-		-	1
Rougher 4	-	-	-	-	-	-		-	2
Condition	y	-	-	-	-	-			
Condition	-	-	-	415	-	-		1	
Rougher	-	-	-	-	60	-			1

Metallurgical Balance

Product	Weight		Grade,%				% Recovery			
	g	%	Cu	Zn	Pb	Fe	Cu	Zn	Pb	Fe
Cu Ro Conc 1	29.9	3.11	12.5	9.06	0.55	24.4	15.8	5.0	13.1	5.6
Cu Ro Conc 2	29.1	3.02	11.0	9.47	0.56	23.4	13.6	5.1	13.0	5.3
Cu Ro Conc 3	38.0	3.95	9.18	9.28	0.31	20.7	14.8	6.5	9.4	6.1
Cu Ro Conc 4	41.1	4.27	5.52	10.4	0.43	20.0	9.6	7.8	14.1	6.4
Zn Ro Conc	116.8	12.13	5.18	27.6	0.24	21.9	25.6	59.1	22.3	19.8
Tail	708.1	73.53	0.69	1.28	0.05	10.4	20.7	16.6	28.2	56.9
Head (calc.)	963.1	100.00	2.45	5.67	0.13	13.4	100.0	100.0	100.0	100.0

Calculated Balance

Cu Ro Conc 1	29.9	3.11	12.5	9.06	0.55	24.4	15.8	5.0	13.1	5.6
Cu Ro Conc 1-2	59.1	6.13	11.8	9.26	0.55	23.9	29.4	10.0	26.1	10.9
Cu Ro Conc 1-4	138.2	14.35	9.19	9.61	0.45	21.9	53.7	24.3	49.5	23.3

Dec 6/92 Test: 37

Pulp Potential: -150
(mV vs Ag/AgCl)
Flotation Gas: Air

Stage	Reagents (g/t)						Time (min)		
	CaO	R208/ 3418	MIBC	CuSO4	SEX	SO2	Grind	Cond	Froth
Grind	-	-	-				43		
Aeration									
Rougher-1	100	10/25	10	-	-	450		-	0.5
Rougher-2	-	-	-	-	-	-		-	0.5
Rougher-3	-	-	-	-	-	-		-	1
Rougher 4	-	-	-	-	-	-		-	2
Condition	y	-	-	-	-	-			
Condition	-	-	-	415	-	-		1	
Rougher	-	-	-	-	60	-			1

Metallurgical Balance

Product	Weight		Grade,%				% Recovery			
	g	%	Cu	Zn	Pb	Fe	Cu	Zn	Pb	Fe
Cu Ro Conc 1	56.3	5.91	15.1	6.81	0.93	28.0	33.5	7.3	36.5	12.3
Cu Ro Conc 2	62.2	6.53	10.8	9.14	0.56	26.5	26.4	10.8	24.3	12.8
Cu Ro Conc 3	63.3	6.65	7.68	11.3	0.27	24.8	19.2	13.6	11.9	12.2
Cu Ro Conc 4	66.9	7.03	3.53	13.0	0.25	24.6	9.3	16.6	11.7	12.8
Zn Ro Conc	39.7	4.17	1.23	44.9	0.06	12.4	1.9	33.9	1.7	3.8
Tail	663.6	69.71	0.37	1.41	0.03	8.89	9.7	17.8	13.9	46.0
Head (calc.)	951.9	100.00	2.67	5.52	0.15	13.5	100.0	100.0	100.0	100.0

Calculated Balance

Cu Ro Conc 1	56.3	5.91	15.1	6.81	0.93	28.0	33.5	7.3	36.5	12.3
Cu Ro Conc 1-2	118.4	12.44	12.8	8.03	0.74	27.2	59.9	18.1	60.8	25.1
Cu Ro Conc 1-4	248.7	26.12	9.02	10.2	0.49	25.9	88.4	48.3	84.4	50.2

Dec 6/92 Test: 38

Pulp Potential: -25
(mV vs Ag/AgCl)
Flotation Gas: Air

Stage	Reagents (g/t)						Time (min)		
	CaO	R208/ 3418	MIBC	CuSO4	SEX	SO2	Grind	Cond	Froth
Grind	-	-	-				43		
Aeration									
Rougher-1	100	10/25	10	-	-	450		-	0.5
Rougher-2	-	-	-	-	-	-		-	0.5
Rougher-3	-	-	-	-	-	-		-	1
Rougher 4	-	-	-	-	-	-		-	2
Condition	y	-	-	-	-	-			
Condition	-	-	-	415	-	-		1	
Rougher	-	-	-	-	60	-			1

Metallurgical Balance

Product	Weight		Grade,%				% Recovery			
	g	%	Cu	Zn	Pb	Fe	Cu	Zn	Pb	Fe
Cu Ro Conc 1	78.6	7.97	12.3	9.07	0.67	26.0	37.3	11.9	38.4	15.4
Cu Ro Conc 2	52.8	5.35	10.3	12.2	0.50	24.8	21.0	10.7	19.2	9.9
Cu Ro Conc 3	69.9	7.09	7.25	13.3	0.24	22.6	19.5	15.5	12.2	11.9
Cu Ro Conc 4	72.2	7.33	3.19	13.1	0.24	23.0	8.9	15.8	12.6	12.5
Zn Ro Conc	43.3	4.39	1.08	38.5	0.09	17.1	1.8	27.8	2.8	5.6
Tail	669.1	67.87	0.45	1.65	0.03	8.89	11.6	18.4	14.6	44.8
Head (calc.)	985.9	100.00	2.63	6.09	0.14	13.5	100.0	100.0	100.0	100.0

Calculated Balance

Cu Ro Conc 1	78.6	7.97	12.3	9.07	0.67	26.0	37.3	11.9	38.4	15.4
Cu Ro Conc 1-2	131.4	13.33	11.5	10.3	0.60	25.5	58.2	22.6	57.7	25.2
Cu Ro Conc 1-4	273.5	27.74	8.22	11.8	0.41	24.1	86.6	53.8	82.5	49.6

Dec 6/92 Test: 39

Pulp Potential: -220
(mV vs Ag/AgCl)
Flotation Gas: Air

Stage	Reagents (g/t)						Time (min)		
	CaO	R208/ 3418	MIBC	CuSO4	SEX	SO2	Grind	Cond	Froth
Grind	-	-	-				43		
Aeration									
Rougher-1	100	10/25	10	-	-	450		-	0.5
Rougher-2	-	-	-	-	-	-		-	0.5
Rougher-3	-	-	-	-	-	-		-	1
Rougher 4	-	-	-	-	-	-		-	2
Condition	y	-	-	-	-	-			
Condition	-	-	-	415	-	-		1	
Rougher	-	-	-	-	60	-			1

Metallurgical Balance

Product	Weight		Grade,%				% Recovery			
	g	%	Cu	Zn	Pb	Fe	Cu	Zn	Pb	Fe
Cu Ro Conc 1	43.2	4.61	7.29	4.04	0.67	30.4	13.2	3.7	22.8	10.3
Cu Ro Conc 2	54.8	5.84	11.0	6.19	0.66	28.0	25.2	7.2	28.5	12.0
Cu Ro Conc 3	60.2	6.42	9.74	8.46	0.32	25.2	24.5	10.9	15.2	11.9
Cu Ro Conc 4	68.4	7.29	6.33	11.8	0.25	24.6	18.1	17.2	13.5	13.1
Zn Ro Conc	60.6	6.46	3.38	37.5	0.10	15.2	8.5	48.5	4.8	7.2
Tail	650.5	69.38	0.39	0.89	0.03	8.96	10.6	12.4	15.4	45.6
Head (calc.)	937.6	100.00	2.55	4.99	0.14	13.6	100.0	100.0	100.0	100.0

Calculated Balance

Cu Ro Conc 1	43.2	4.61	7.29	4.04	0.67	30.4	13.2	3.7	22.8	10.3
Cu Ro Conc 1-2	98.0	10.45	9.36	5.24	0.66	29.1	38.3	11.0	51.3	22.3
Cu Ro Conc 1-4	226.5	24.16	8.55	8.08	0.45	26.7	80.9	39.1	79.9	47.2

Dec 6/92 Test: 40

Pulp Potential: 0
(mV vs Ag/AgCl)
Flotation Gas: Air

Stage	Reagents (g/t)						Time (min)		
	CaO	R208/ 3418	MIBC	CuSO4	SEX	SO2	Grind	Cond	Froth
Grind	-	-	-				43		
Aeration									
Rougher-1	100	10/25	10	-	-	450		-	0.5
Rougher-2	-	-	-	-	-	-		-	0.5
Rougher-3	-	-	-	-	-	-		-	1
Rougher 4	-	-	-	-	-	-		-	2
Condition	y	-	-	-	-	-			
Condition	-	-	-	415	-	-		1	
Rougher	-	-	-	-	60	-			1

Metallurgical Balance

Product	Weight		Grade,%				% Recovery			
	g	%	Cu	Zn	Pb	Fe	Cu	Zn	Pb	Fe
Cu Ro Conc 1	87.4	9.17	11.4	10.0	0.63	25.1	39.6	16.2	40.4	16.7
Cu Ro Conc 2	66.9	7.02	10.2	13.0	0.47	25.7	27.1	16.1	23.1	13.1
Cu Ro Conc 3	54.8	5.76	6.93	15.1	0.25	23.6	15.1	15.4	10.1	9.9
Cu Ro Conc 4	48.8	5.12	3.42	14.3	0.24	25.0	6.6	13.0	8.6	9.3
Zn Ro Conc	44.6	4.68	1.03	33.5	0.11	20.6	1.8	27.7	3.6	7.0
Tail	650.2	68.25	0.38	0.96	0.03	8.85	9.8	11.6	14.3	43.9
Head (calc.)	952.7	100.00	2.64	5.65	0.14	13.7	100.0	100.0	100.0	100.0

Calculated Balance

Cu Ro Conc 1	87.4	9.17	11.4	10.0	0.63	25.1	39.6	16.2	40.4	16.7
Cu Ro Conc 1-2	154.3	16.19	10.9	11.3	0.56	25.4	66.6	32.4	63.4	29.9
Cu Ro Conc 1-4	257.9	27.07	8.63	12.7	0.43	24.9	88.4	60.7	82.1	49.1

Dec 6/92 Test: 41

Pulp Potential: -100
(mV vs Ag/AgCl)
Flotation Gas: Air

Stage	Reagents (g/t)						Time (min)		
	CaO	R208/ 3418	MIBC	CuSO4	SEX	SO2	Grind	Cond	Froth
Grind	-	-	-				43		
Aeration									
Rougher-1	100	10/25	10	-	-	450		-	0.5
Rougher-2	-	-	-	-	-	-		-	0.5
Rougher-3	-	-	-	-	-	-		-	1
Rougher 4	-	-	-	-	-	-		-	2
Condition	y	-	-	-	-	-			
Condition	-	-	-	415	-	-		1	
Rougher	-	-	-	-	60	-			1

Metallurgical Balance

Product	Weight		Grade,%				% Recovery			
	g	%	Cu	Zn	Pb	Fe	Cu	Zn	Pb	Fe
Cu Ro Conc 1	52.6	5.62	14.4	6.86	0.85	27.1	30.4	7.0	32.1	11.3
Cu Ro Conc 2	53.0	5.67	11.3	9.48	0.56	25.9	24.1	9.7	21.4	10.9
Cu Ro Conc 3	71.2	7.61	7.93	12.2	0.27	23.5	22.7	16.8	13.8	13.3
Cu Ro Conc 4	68.6	7.34	3.85	13.7	0.25	23.6	10.6	18.1	12.3	12.8
Zn Ro Conc	37.5	4.01	1.20	42.8	0.06	12.6	1.8	30.9	1.6	3.7
Tail	651.9	69.75	0.40	1.39	0.04	9.27	10.5	17.5	18.8	47.9
Head (calc.)	934.7	100.00	2.66	5.54	0.15	13.5	100.0	100.0	100.0	100.0

Calculated Balance

Cu Ro Conc 1	52.6	5.62	14.4	6.86	0.85	27.1	30.4	7.0	32.1	11.3
Cu Ro Conc 1-2	105.6	11.30	12.8	8.18	0.70	26.5	54.5	16.7	53.5	22.2
Cu Ro Conc 1-4	245.3	26.25	8.90	10.9	0.45	24.8	87.7	51.6	79.6	48.3

Dec 6/92 Test: 42

Pulp Potential: 25
(mV vs Ag/AgCl)
Flotation Gas: Air

Stage	Reagents (g/t)						Time (min)		
	CaO	R208/ 3418	MIBC	CuSO4	SEX	SO2	Grind	Cond	Froth
Grind	-	-	-				43		
Aeration									
Rougher-1	100	10/25	10	-	-	450		-	0.5
Rougher-2	-	-	-	-	-	-		-	0.5
Rougher-3	-	-	-	-	-	-		-	1
Rougher 4	-	-	-	-	-	-		-	2
Condition	y	-	-	-	-	-			
Condition	-	-	-	415	-	-		1	
Rougher	-	-	-	-	60	-			1

Metallurgical Balance

Product	Weight		Grade,%				% Recovery			
	g	%	Cu	Zn	Pb	Fe	Cu	Zn	Pb	Fe
Cu Ro Conc 1	86.5	9.07	10.8	6.39	0.65	26.4	42.4	11.5	30.5	18.1
Cu Ro Conc 2	48.9	5.13	8.24	9.75	0.36	22.0	18.3	9.9	9.5	8.5
Cu Ro Conc 3	80.4	8.42	5.59	12.1	0.22	22.9	20.4	20.2	9.6	14.6
Cu Ro Conc 4	69.6	7.29	2.54	12.2	0.12	20.6	8.0	17.6	4.5	11.4
Zn Ro Conc	32.0	3.35	0.72	41.7	0.06	12.4	1.0	27.7	1.0	3.1
Tail	636.9	66.74	0.34	1.00	0.13	8.77	9.8	13.2	44.9	44.3
Head (calc.)	954.3	100.00	2.31	5.05	0.19	13.2	100.0	100.0	100.0	100.0

Calculated Balance

Cu Ro Conc 1	86.5	9.07	10.8	6.39	0.65	26.4	42.4	11.5	30.5	18.1
Cu Ro Conc 1-2	135.4	14.19	9.88	7.60	0.55	24.8	60.7	21.4	40.0	26.6
Cu Ro Conc 1-4	285.4	29.90	6.88	9.99	0.35	23.2	89.1	59.1	54.1	52.6

Dec 7/92 Test: 43

Pulp Potential: -50
(mV vs Ag/AgCl)
Flotation Gas: Air

Stage	Reagents (g/t)						Time (min)		
	CaO	R208/ 3418	MIBC	CuSO4	SEX	SO2	Grind	Cond	Froth
Grind	-	-	-				43		
Aeration									
Rougher-1	100	10/25	10	-	-	450		-	0.5
Rougher-2	-	-	-	-	-	-		-	0.5
Rougher-3	-	-	-	-	-	-		-	1
Rougher 4	-	-	-	-	-	-		-	2
Condition	y	-	-	-	-	-			
Condition	-	-	-	415	-	-		1	
Rougher	-	-	-	-	60	-			1

Metallurgical Balance

Product	Weight		Grade,%				% Recovery			
	g	%	Cu	Zn	Pb	Fe	Cu	Zn	Pb	Fe
Cu Ro Conc 1	72.4	7.70	11.5	8.33	0.67	24.7	39.0	12.8	38.0	14.3
Cu Ro Conc 2	52.2	5.56	8.43	11.6	0.36	21.2	20.6	12.9	14.7	8.8
Cu Ro Conc 3	60.7	6.45	6.33	13.4	0.25	21.7	18.0	17.2	11.9	10.5
Cu Ro Conc 4	59.3	6.31	3.45	13.0	0.16	21.2	9.6	16.3	7.4	10.0
Zn Ro Conc	33.1	3.52	0.89	39.2	0.08	16.6	1.4	27.5	2.1	4.4
Tail	662.6	70.46	0.37	0.95	0.05	9.81	11.5	13.3	25.9	51.9
Head (calc.)	940.3	100.00	2.27	5.02	0.14	13.3	100.0	100.0	100.0	100.0

Calculated Balance

Cu Ro Conc 1	72.4	7.70	11.5	8.33	0.67	24.7	39.0	12.8	38.0	14.3
Cu Ro Conc 1-2	124.7	13.26	10.2	9.72	0.54	23.2	59.6	25.7	52.7	23.1
Cu Ro Conc 1-4	244.6	26.02	7.61	11.4	0.38	22.4	87.1	59.2	72.0	43.7

Dec 7/92 Test: 44

Pulp Potential: -220
(mV vs Ag/AgCl)
Flotation Gas: Nitrogen

Stage	Reagents (g/t)						Time (min)		
	CaO	3418	MIBC	CuSO4	SEX	SO2	Grind	Cond	Froth
Grind	-	-	-				43		
Aeration									
Rougher-1	-	-	10	-	-	450		-	0.5
Rougher-2	-	-	-	-	-	-		-	0.5
Rougher-3	-	-	-	-	-	-		-	1
Rougher 4	-	-	-	-	-	-		-	2
Condition	y	-	-	-	-	-			
Condition	-	-	-	415	-	-		1	
Rougher	-	-	-	-	60	-			1

Metallurgical Balance

Product	Weight		Grade,%				% Recovery			
	g	%	Cu	Zn	Pb	Fe	Cu	Zn	Pb	Fe
Cu Ro Conc 1	42.0	4.38	3.78	7.35	0.75	20.9	6.9	6.4	25.5	6.6
Cu Ro Conc 2	27.1	2.82	4.65	6.39	0.35	18.5	5.5	3.6	7.7	3.8
Cu Ro Conc 3	36.8	3.84	3.90	6.43	0.32	18.7	6.3	4.9	9.5	5.2
Cu Ro Conc 4	46.2	4.82	2.51	5.73	0.21	16.3	5.1	5.5	7.9	5.7
Zn Ro Conc	73.5	7.67	10.5	23.0	0.13	18.7	33.8	35.0	7.8	10.4
Tail	732.8	76.47	1.32	2.95	0.07	12.4	42.4	44.7	41.6	68.4
Head (calc.)	958.3	100.00	2.38	5.05	0.13	13.9	100.0	100.0	100.0	100.0

Calculated Balance

Cu Ro Conc 1	42.0	4.38	3.78	7.35	0.75	20.9	6.9	6.4	25.5	6.6
Cu Ro Conc 1-2	69.0	7.20	4.12	6.97	0.59	20.0	12.5	10.0	33.2	10.4
Cu Ro Conc 1-4	152.0	15.86	3.58	6.46	0.41	18.5	23.8	20.3	50.6	21.2

Dec 7/92 Test: 45

Pulp Potential: -25
(mV vs Ag/AgCl)
Flotation Gas: Nitrogen

Stage	Reagents (g/t)						Time (min)		
	CaO	3418	MIBC	CuSO4	SEX	SO2	Grind	Cond	Froth
Grind	-	-	-				43		
Aeration									
Rougher-1	-	-	10	-	-	450		-	0.5
Rougher-2	-	-	-	-	-	-		-	0.5
Rougher-3	-	-	-	-	-	-		-	1
Rougher 4	-	-	-	-	-	-		-	2
Condition	y	-	-	-	-	-			
Condition	-	-	-	415	-	-		1	
Rougher	-	-	-	-	60	-			1

Metallurgical Balance

Product	Weight		Grade,%				% Recovery			
	g	%	Cu	Zn	Pb	Fe	Cu	Zn	Pb	Fe
Cu Ro Conc 1	39.0	4.09	10.6	7.84	0.75	23.4	18.8	6.1	26.2	6.9
Cu Ro Conc 2	28.6	3.00	8.38	7.40	0.33	20.1	10.9	4.2	8.5	4.3
Cu Ro Conc 3	40.0	4.19	6.16	6.99	0.29	18.9	11.2	5.6	10.4	5.7
Cu Ro Conc 4	44.6	4.68	3.17	5.74	0.22	16.9	6.4	5.1	8.8	5.7
Zn Ro Conc	88.8	9.32	5.14	29.8	0.18	22.2	20.8	53.0	14.3	14.8
Tail	712.4	74.72	0.98	1.82	0.05	11.7	31.8	25.9	31.9	62.6
Head (calc.)	953.5	100.00	2.30	5.24	0.12	14.0	100.0	100.0	100.0	100.0

Calculated Balance

Cu Ro Conc 1	39.0	4.09	10.6	7.84	0.75	23.4	18.8	6.1	26.2	6.9
Cu Ro Conc 1-2	67.7	7.10	9.66	7.65	0.57	22.0	29.8	10.4	34.7	11.2
Cu Ro Conc 1-4	152.2	15.97	6.84	6.92	0.39	19.7	47.4	21.1	53.8	22.5

Dec 7/92 Test: 46

Pulp Potential: -100
(mV vs Ag/AgCl)
Flotation Gas: Nitrogen

Stage	Reagents (g/t)						Time (min)		
	CaO	3418	MIBC	CuSO4	SEX	SO2	Grind	Cond	Froth
Grind	-	-	-				43		
Aeration									
Rougher-1	-	-	10	-	-	450		-	0.5
Rougher-2	-	-	-	-	-	-		-	0.5
Rougher-3	-	-	-	-	-	-		-	1
Rougher 4	-	-	-	-	-	-		-	2
Condition	y	-	-	-	-	-			
Condition	-	-	-	415	-	-		1	
Rougher	-	-	-	-	60	-			1

Metallurgical Balance

Product	Weight		Grade,%				% Recovery			
	g	%	Cu	Zn	Pb	Fe	Cu	Zn	Pb	Fe
Cu Ro Conc 1	29.9	3.16	7.92	7.39	0.68	22.4	10.7	4.6	19.5	5.1
Cu Ro Conc 2	23.7	2.50	6.70	6.56	0.35	19.0	7.1	3.2	8.0	3.4
Cu Ro Conc 3	36.6	3.87	5.71	6.61	0.31	18.9	9.4	5.0	10.9	5.3
Cu Ro Conc 4	42.9	4.54	3.96	6.05	0.22	18.2	7.7	5.4	9.1	5.9
Zn Ro Conc	64.3	6.80	8.30	31.1	0.15	16.7	24.0	41.5	9.3	8.2
Tail	748.6	79.13	1.22	2.59	0.06	12.7	41.1	40.2	43.2	72.2
Head (calc.)	946.1	100.00	2.35	5.09	0.11	13.9	100.0	100.0	100.0	100.0

Calculated Balance

Cu Ro Conc 1	29.9	3.16	7.92	7.39	0.68	22.4	10.7	4.6	19.5	5.1
Cu Ro Conc 1-2	53.6	5.66	7.38	7.02	0.53	20.9	17.8	7.8	27.5	8.5
Cu Ro Conc 1-4	133.1	14.07	5.82	6.60	0.37	19.5	34.9	18.2	47.5	19.7

Dec 8/92 Test: 47

Pulp Potential: 25
(mV vs Ag/AgCl)
Flotation Gas: Nitrogen

Stage	Reagents (g/t)						Time (min)		
	CaO	3418	MIBC	CuSO4	SEX	SO2	Grind	Cond	Froth
Grind	-	-	-				43		
Aeration									
Rougher-1	-	-	10	-	-	450		-	0.5
Rougher-2	-	-	-	-	-	-		-	0.5
Rougher-3	-	-	-	-	-	-		-	1
Rougher 4	-	-	-	-	-	-		-	2
Condition	y	-	-	-	-	-			
Condition	-	-	-	415	-	-		1	
Rougher	-	-	-	-	60	-			1

Metallurgical Balance

Product	Weight		Grade,%				% Recovery			
	g	%	Cu	Zn	Pb	Fe	Cu	Zn	Pb	Fe
Cu Ro Conc 1	33.9	3.67	11.7	7.74	0.57	23.4	19.1	5.4	19.0	6.1
Cu Ro Conc 2	29.4	3.18	9.41	7.72	0.30	20.0	13.3	4.6	8.7	4.5
Cu Ro Conc 3	38.2	4.14	7.12	7.85	0.25	18.3	13.1	6.1	9.4	5.4
Cu Ro Conc 4	49.2	5.33	4.46	7.10	0.19	17.6	10.6	7.1	9.2	6.6
Zn Ro Conc	70.6	7.64	3.79	34.0	0.28	18.6	12.9	49.0	19.4	10.1
Tail	702.1	76.03	0.92	1.94	0.05	12.5	31.1	27.8	34.4	67.3
Head (calc.)	923.5	100.00	2.25	5.31	0.11	14.1	100.0	100.0	100.0	100.0

Calculated Balance

Cu Ro Conc 1	33.9	3.67	11.7	7.74	0.57	23.4	19.1	5.4	19.0	6.1
Cu Ro Conc 1-2	63.3	6.86	10.6	7.73	0.44	21.8	32.4	10.0	27.6	10.6
Cu Ro Conc 1-4	150.8	16.33	7.73	7.56	0.31	19.5	56.1	23.2	46.2	22.6

Dec 8/92 Test: 48

Pulp Potential: -150
(mV vs Ag/AgCl)
Flotation Gas: Nitrogen

Stage	Reagents (g/t)						Time (min)		
	CaO	3418	MIBC	CuSO4	SEX	SO2	Grind	Cond	Froth
Grind	-	-	-				43		
Aeration									
Rougher-1	-	-	10	-	-	450		-	0.5
Rougher-2	-	-	-	-	-	-		-	0.5
Rougher-3	-	-	-	-	-	-		-	1
Rougher 4	-	-	-	-	-	-		-	2
Condition	y	-	-	-	-	-			
Condition	-	-	-	415	-	-		1	
Rougher	-	-	-	-	60	-			1

Metallurgical Balance

Product	Weight		Grade,%				% Recovery			
	g	%	Cu	Zn	Pb	Fe	Cu	Zn	Pb	Fe
Cu Ro Conc 1	33.0	3.47	6.51	6.77	0.59	22.6	9.1	4.3	18.8	5.5
Cu Ro Conc 2	23.8	2.50	5.96	6.19	0.33	19.0	6.0	2.9	7.6	3.3
Cu Ro Conc 3	37.5	3.94	5.09	6.19	0.31	18.7	8.1	4.5	11.2	5.2
Cu Ro Conc 4	36.4	3.82	3.74	6.17	0.19	17.6	5.8	4.4	6.7	4.7
Zn Ro Conc	77.5	8.14	9.04	25.4	0.17	19.8	29.7	38.2	12.7	11.3
Tail	744.1	78.14	1.31	3.16	0.06	12.7	41.3	45.7	43.1	69.9
Head (calc.)	952.3	100.00	2.48	5.41	0.11	14.2	100.0	100.0	100.0	100.0

Calculated Balance

Cu Ro Conc 1	33.0	3.47	6.51	6.77	0.59	22.6	9.1	4.3	18.8	5.5
Cu Ro Conc 1-2	56.9	5.97	6.28	6.53	0.48	21.1	15.1	7.2	26.4	8.9
Cu Ro Conc 1-4	130.7	13.73	5.23	6.33	0.35	19.4	29.0	16.1	44.2	18.8

Dec 8/92 Test: 49

Pulp Potential: 0
(mV vs Ag/AgCl)
Flotation Gas: Nitrogen

Stage	Reagents (g/t)						Time (min)		
	CaO	3418	MIBC	CuSO4	SEX	SO2	Grind	Cond	Froth
Grind	-	-	-				43		
Aeration									
Rougher-1	-	-	10	-	-	450		-	0.5
Rougher-2	-	-	-	-	-	-		-	0.5
Rougher-3	-	-	-	-	-	-		-	1
Rougher 4	-	-	-	-	-	-		-	2
Condition	y	-	-	-	-	-			
Condition	-	-	-	415	-	-		1	
Rougher	-	-	-	-	60	-			1

Metallurgical Balance

Product	Weight		Grade,%				% Recovery			
	g	%	Cu	Zn	Pb	Fe	Cu	Zn	Pb	Fe
Cu Ro Conc 1	34.5	3.67	9.91	7.36	0.51	23.0	16.4	5.3	17.2	6.1
Cu Ro Conc 2	34.1	3.62	8.23	7.11	0.29	19.4	13.4	5.1	9.7	5.1
Cu Ro Conc 3	34.6	3.68	6.31	6.93	0.27	18.7	10.4	5.0	9.1	5.0
Cu Ro Conc 4	41.3	4.40	3.67	6.14	0.23	17.1	7.3	5.3	9.3	5.4
Zn Ro Conc	62.3	6.62	4.58	34.1	0.19	18.0	13.6	44.6	11.6	8.6
Tail	733.3	78.01	1.11	2.25	0.06	12.4	38.9	34.6	43.1	69.8
Head (calc.)	940.1	100.00	2.22	5.07	0.11	13.9	100.0	100.0	100.0	100.0

Calculated Balance

Cu Ro Conc 1	34.5	3.67	9.91	7.36	0.51	23.0	16.4	5.3	17.2	6.1
Cu Ro Conc 1-2	68.6	7.30	9.08	7.24	0.40	21.2	29.8	10.4	26.9	11.2
Cu Ro Conc 1-4	144.5	15.37	6.87	6.85	0.32	19.4	47.4	20.8	45.3	21.6

Dec 8/92 Test: 51

Pulp Potential: -220
(mV vs Ag/AgCl)
Flotation Gas: Nitrogen

Stage	Reagents (g/t)						Time (min)		
	CaO	3418	MIBC	CuSO4	SEX	SO2	Grind	Cond	Froth
Grind	-	-	-				43		
Aeration									
Rougher-1	100	-	10	-	-	450		-	0.5
Rougher-2	-	-	-	-	-	-		-	0.5
Rougher-3	-	-	-	-	-	-		-	1
Rougher 4	-	-	-	-	-	-		-	2
Condition	y	-	-	-	-	-			
Condition	-	-	-	415	-	-		1	
Rougher	-	-	-	-	60	-			1

Metallurgical Balance

Product	Weight		Grade,%				% Recovery			
	g	%	Cu	Zn	Pb	Fe	Cu	Zn	Pb	Fe
Cu Ro Conc 1	21.3	2.32	1.49	6.32	0.84	19.9	1.3	2.8	16.2	3.2
Cu Ro Conc 2	19.7	2.14	2.39	5.72	0.45	19.0	2.0	2.3	8.0	2.8
Cu Ro Conc 3	28.5	3.10	2.22	5.56	0.43	17.6	2.6	3.2	11.1	3.8
Cu Ro Conc 4	33.8	3.67	2.15	5.23	0.30	16.2	3.0	3.6	9.2	4.1
Zn Ro Conc	105.0	11.42	7.26	16.5	0.18	26.6	31.9	35.4	17.1	20.9
Tail	710.8	77.34	1.99	3.62	0.06	12.3	59.2	52.6	38.5	65.3
Head (calc.)	919.0	100.00	2.60	5.32	0.12	14.6	100.0	100.0	100.0	100.0

Calculated Balance

Cu Ro Conc 1	21.3	2.32	1.49	6.32	0.84	19.9	1.3	2.8	16.2	3.2
Cu Ro Conc 1-2	41.0	4.46	1.92	6.03	0.65	19.5	3.3	5.1	24.2	6.0
Cu Ro Conc 1-4	103.3	11.24	2.08	5.64	0.48	17.9	9.0	11.9	44.4	13.8

Dec 9/92 Test: 52

Pulp Potential: -100
(mV vs Ag/AgCl)
Flotation Gas: Nitrogen

Stage	Reagents (g/t)						Time (min)		
	CaO	3418	MIBC	CuSO4	SEX	SO2	Grind	Cond	Froth
Grind	-	-	-				43		
Aeration									
Rougher-1	100	-	10	-	-	450		-	0.5
Rougher-2	-	-	-	-	-	-		-	0.5
Rougher-3	-	-	-	-	-	-		-	1
Rougher 4	-	-	-	-	-	-		-	2
Condition	y	-	-	-	-	-			
Condition	-	-	-	415	-	-		1	
Rougher	-	-	-	-	60	-			1

Metallurgical Balance

Product	Weight		Grade,%				% Recovery			
	g	%	Cu	Zn	Pb	Fe	Cu	Zn	Pb	Fe
Cu Ro Conc 1	38.7	4.01	6.59	6.30	0.63	21.9	10.6	4.7	20.6	6.3
Cu Ro Conc 2	22.6	2.33	7.29	5.92	0.37	19.9	6.8	2.6	7.0	3.3
Cu Ro Conc 3	33.0	3.41	5.04	5.88	0.35	17.8	6.9	3.7	9.7	4.3
Cu Ro Conc 4	31.1	3.22	3.07	5.71	0.30	16.7	4.0	3.4	7.9	3.8
Zn Ro Conc	75.4	7.80	9.92	29.2	0.15	18.4	31.0	42.1	9.5	10.3
Tail	765.6	79.23	1.28	2.97	0.07	12.7	40.7	43.5	45.2	72.0
Head (calc.)	966.3	100.00	2.49	5.41	0.12	14.0	100.0	100.0	100.0	100.0

Calculated Balance

Cu Ro Conc 1	38.7	4.01	6.59	6.30	0.63	21.9	10.6	4.7	20.6	6.3
Cu Ro Conc 1-2	61.3	6.34	6.85	6.16	0.53	21.2	17.4	7.2	27.6	9.6
Cu Ro Conc 1-4	125.3	12.97	5.43	5.97	0.43	19.2	28.3	14.3	45.2	17.8

Dec 9/92 Test: 53

Pulp Potential: -25
(mV vs Ag/AgCl)
Flotation Gas: Nitrogen

Stage	Reagents (g/t)						Time (min)		
	CaO	3418	MIBC	CuSO4	SEX	SO2	Grind	Cond	Froth
Grind	-	-	-				43		
Aeration									
Rougher-1	100	-	10	-	-	450		-	0.5
Rougher-2	-	-	-	-	-	-		-	0.5
Rougher-3	-	-	-	-	-	-		-	1
Rougher 4	-	-	-	-	-	-		-	2
Condition	y	-	-	-	-	-			
Condition	-	-	-	415	-	-		1	
Rougher	-	-	-	-	60	-			1

Metallurgical Balance

Product	Weight		Grade,%				% Recovery			
	g	%	Cu	Zn	Pb	Fe	Cu	Zn	Pb	Fe
Cu Ro Conc 1	41.9	4.69	10.4	8.22	0.53	22.3	20.5	6.6	22.4	7.3
Cu Ro Conc 2	36.5	4.08	9.12	8.53	0.29	18.7	15.6	6.0	10.7	5.3
Cu Ro Conc 3	40.8	4.57	7.01	8.36	0.24	18.3	13.4	6.6	9.9	5.8
Cu Ro Conc 4	43.3	4.85	5.10	7.61	0.19	17.7	10.4	6.3	8.3	6.0
Zn Ro Conc	91.0	10.19	3.68	29.9	0.25	22.0	15.7	52.3	23.0	15.6
Tail	639.9	71.62	0.81	1.80	0.04	12.0	24.3	22.1	25.8	59.9
Head (calc.)	893.5	100.00	2.38	5.82	0.11	14.3	100.0	100.0	100.0	100.0

Calculated Balance

Cu Ro Conc 1	41.9	4.69	10.4	8.22	0.53	22.3	20.5	6.6	22.4	7.3
Cu Ro Conc 1-2	78.3	8.77	9.80	8.36	0.42	20.6	36.1	12.6	33.0	12.6
Cu Ro Conc 1-4	162.5	18.19	7.85	8.16	0.31	19.3	59.9	25.5	51.2	24.4

Dec 9/92 Test: 54

Pulp Potential: 25
(mV vs Ag/AgCl)
Flotation Gas: Nitrogen

Stage	Reagents (g/t)						Time (min)		
	CaO	3418	MIBC	CuSO4	SEX	SO2	Grind	Cond	Froth
Grind	-	-	-				43		
Aeration									
Rougher-1	100	-	10	-	-	450		-	0.5
Rougher-2	-	-	-	-	-	-		-	0.5
Rougher-3	-	-	-	-	-	-		-	1
Rougher 4	-	-	-	-	-	-		-	2
Condition	y	-	-	-	-	-			
Condition	-	-	-	415	-	-		1	
Rougher	-	-	-	-	60	-			1

Metallurgical Balance

Product	Weight		Grade,%				% Recovery			
	g	%	Cu	Zn	Pb	Fe	Cu	Zn	Pb	Fe
Cu Ro Conc 1	52.1	5.58	10.1	8.01	0.54	21.9	25.1	8.0	25.5	8.5
Cu Ro Conc 2	36.3	3.88	8.29	8.27	0.29	18.7	14.3	5.7	9.5	5.1
Cu Ro Conc 3	42.4	4.54	6.83	8.64	0.24	18.3	13.8	7.0	9.2	5.8
Cu Ro Conc 4	50.0	5.36	4.43	8.07	0.18	16.9	10.6	7.7	8.2	6.3
Zn Ro Conc	124.2	13.31	3.12	24.7	0.27	26.0	18.5	58.8	30.4	24.1
Tail	628.2	67.32	0.59	1.06	0.03	10.7	17.7	12.8	17.1	50.2
Head (calc.)	933.1	100.00	2.25	5.59	0.12	14.3	100.0	100.0	100.0	100.0

Calculated Balance

Cu Ro Conc 1	52.1	5.58	10.1	8.01	0.54	21.9	25.1	8.0	25.5	8.5
Cu Ro Conc 1-2	88.3	9.47	9.36	8.12	0.44	20.6	39.4	13.7	35.1	13.6
Cu Ro Conc 1-4	180.7	19.36	7.40	8.23	0.32	19.0	63.8	28.5	52.5	25.7

Dec 9/92 Test: 56

Pulp Potential: -25
(mV vs Ag/AgCl)
Flotation Gas: Nitrogen

Stage	Reagents (g/t)						Time (min)		
	CaO	R208/ 3418	MIBC	CuSO4	SEX	SO2	Grind	Cond	Froth
Grind	-	-	-				43		
Aeration									
Rougher-1	100	10/25	10	-	-	450		-	0.5
Rougher-2	-	-	-	-	-	-		-	0.5
Rougher-3	-	-	-	-	-	-		-	1
Rougher 4	-	-	-	-	-	-		-	2
Condition	y	-	-	-	-	-			
Condition	-	-	-	415	-	-		1	
Rougher	-	-	-	-	60	-			1

Metallurgical Balance

Product	Weight		Grade,%				% Recovery			
	g	%	Cu	Zn	Pb	Fe	Cu	Zn	Pb	Fe
Cu Ro Conc 1	88.0	9.61	11.0	9.87	0.54	23.3	43.1	17.4	45.7	16.3
Cu Ro Conc 2	60.2	6.57	7.59	11.5	0.29	21.1	20.3	13.9	16.8	10.1
Cu Ro Conc 3	74.1	8.08	4.88	10.5	0.21	21.1	16.1	15.6	15.0	12.4
Cu Ro Conc 4	49.7	5.43	3.11	8.63	0.15	21.4	6.9	8.6	7.2	8.4
Zn Ro Conc	43.8	4.78	1.10	36.6	0.09	18.0	2.1	32.1	3.8	6.3
Tail	600.4	65.53	0.43	1.03	0.02	9.77	11.5	12.4	11.5	46.5
Head (calc.)	916.3	100.00	2.45	5.45	0.11	13.8	100.0	100.0	100.0	100.0

Calculated Balance

Cu Ro Conc 1	88.0	9.61	11.0	9.87	0.54	23.3	43.1	17.4	45.7	16.3
Cu Ro Conc 1-2	148.3	16.18	9.61	10.5	0.44	22.4	63.4	31.3	62.5	26.4
Cu Ro Conc 1-4	272.1	29.69	7.14	10.2	0.32	21.9	86.4	55.5	84.7	47.2

Dec 11/92 Test: 57

Pulp Potential: -100
(mV vs Ag/AgCl)
Flotation Gas: Nitrogen

Stage	Reagents (g/t)						Time (min)		
	CaO	R208/ 3418	MIBC	CuSO4	SEX	SO2	Grind	Cond	Froth
Grind	-	-	-				43		
Aeration									
Rougher-1	100	10/25	10	-	-	450		-	0.5
Rougher-2	-	-	-	-	-	-		-	0.5
Rougher-3	-	-	-	-	-	-		-	1
Rougher 4	-	-	-	-	-	-		-	2
Condition	y	-	-	-	-	-			
Condition	-	-	-	415	-	-		1	
Rougher	-	-	-	-	60	-			1

Metallurgical Balance

Product	Weight		Grade,%				% Recovery			
	g	%	Cu	Zn	Pb	Fe	Cu	Zn	Pb	Fe
Cu Ro Conc 1	55.7	6.03	13.6	4.30	0.81	26.8	33.2	4.9	40.8	11.7
Cu Ro Conc 2	52.1	5.64	8.66	5.62	0.40	24.1	19.8	6.0	18.9	9.8
Cu Ro Conc 3	72.9	7.90	5.94	6.57	0.28	24.4	19.0	9.8	18.5	13.9
Cu Ro Conc 4	50.2	5.44	3.33	7.39	0.16	21.0	7.3	7.6	7.3	8.2
Zn Ro Conc	55.9	6.05	3.39	37.5	0.06	14.2	8.3	42.9	3.0	6.2
Tail	636.3	68.93	0.44	2.20	0.02	10.1	12.3	28.7	11.5	50.2
Head (calc.)	923.1	100.00	2.47	5.28	0.12	13.9	100.0	100.0	100.0	100.0

Calculated Balance

Cu Ro Conc 1	55.7	6.03	13.6	4.30	0.81	26.8	33.2	4.9	40.8	11.7
Cu Ro Conc 1-2	107.8	11.67	11.2	4.94	0.61	25.5	53.0	10.9	59.7	21.5
Cu Ro Conc 1-4	230.9	25.01	7.83	5.99	0.41	24.2	79.4	28.3	85.4	43.6

Dec 11/92 Test: 58

Pulp Potential: 25
(mV vs Ag/AgCl)
Flotation Gas: Nitrogen

Stage	Reagents (g/t)						Time (min)		
	CaO	R208/ 3418	MIBC	CuSO4	SEX	SO2	Grind	Cond	Froth
Grind	-	-	-				43		
Aeration									
Rougher-1	100	10/25	10	-	-	450		-	0.5
Rougher-2	-	-	-	-	-	-		-	0.5
Rougher-3	-	-	-	-	-	-		-	1
Rougher 4	-	-	-	-	-	-		-	2
Condition	y	-	-	-	-	-			
Condition	-	-	-	415	-	-		1	
Rougher	-	-	-	-	60	-			1

Metallurgical Balance

Product	Weight		Grade,%				% Recovery			
	g	%	Cu	Zn	Pb	Fe	Cu	Zn	Pb	Fe
Cu Ro Conc 1	86.7	10.11	11.6	10.2	0.57	23.8	45.6	17.6	47.6	17.3
Cu Ro Conc 2	62.7	7.31	7.60	12.3	0.30	20.7	21.6	15.4	18.1	10.9
Cu Ro Conc 3	60.4	7.04	4.78	11.8	0.21	21.0	13.1	14.2	12.2	10.6
Cu Ro Conc 4	52.5	6.12	2.94	9.05	0.15	22.3	7.0	9.5	7.6	9.8
Zn Ro Conc	43.6	5.08	1.00	36.6	0.09	18.0	2.0	31.8	3.8	6.6
Tail	551.8	64.34	0.43	1.04	0.02	9.68	10.8	11.4	10.6	44.8
Head (calc.)	857.6	100.00	2.57	5.84	0.12	13.9	100.0	100.0	100.0	100.0

Calculated Balance

Cu Ro Conc 1	86.7	10.11	11.6	10.2	0.57	23.8	45.6	17.6	47.6	17.3
Cu Ro Conc 1-2	149.4	17.42	9.92	11.1	0.46	22.5	67.2	33.0	65.8	28.2
Cu Ro Conc 1-4	262.3	30.58	7.34	10.8	0.34	22.1	87.3	56.7	85.6	48.6

Dec 11/92 Test: 59

Pulp Potential: -150
(mV vs Ag/AgCl)
Flotation Gas: Nitrogen

Stage	Reagents (g/t)						Time (min)		
	CaO	R208/ 3418	MIBC	CuSO4	SEX	SO2	Grind	Cond	Froth
Grind	-	-	-				43		
Aeration									
Rougher-1	100	10/25	10	-	-	450		-	0.5
Rougher-2	-	-	-	-	-	-		-	0.5
Rougher-3	-	-	-	-	-	-		-	1
Rougher 4	-	-	-	-	-	-		-	2
Condition	y	-	-	-	-	-			
Condition	-	-	-	415	-	-		1	
Rougher	-	-	-	-	60	-			1

Metallurgical Balance

Product	Weight		Grade,%				% Recovery			
	g	%	Cu	Zn	Pb	Fe	Cu	Zn	Pb	Fe
Cu Ro Conc 1	74.8	7.80	10.2	4.28	0.74	24.4	37.1	7.4	47.0	14.1
Cu Ro Conc 2	52.6	5.49	7.36	5.59	0.43	23.6	18.8	6.8	19.2	9.6
Cu Ro Conc 3	55.2	5.76	4.82	6.46	0.28	22.0	12.9	8.2	13.1	9.4
Cu Ro Conc 4	42.1	4.39	3.43	7.75	0.18	20.5	7.0	7.5	6.4	6.7
Zn Ro Conc	41.0	4.27	4.20	35.0	0.07	16.8	8.4	32.9	2.4	5.3
Tail	693.0	72.29	0.47	2.34	0.02	10.3	15.8	37.3	11.8	55.0
Head (calc.)	958.7	100.00	2.15	4.54	0.12	13.5	100.0	100.0	100.0	100.0

Calculated Balance

Cu Ro Conc 1	74.8	7.80	10.2	4.28	0.74	24.4	37.1	7.4	47.0	14.1
Cu Ro Conc 1-2	127.4	13.29	9.03	4.82	0.61	24.1	55.9	14.1	66.2	23.6
Cu Ro Conc 1-4	224.7	23.44	6.94	5.77	0.45	22.9	75.8	29.8	85.8	39.7

Dec 11/92 Test: 60

Pulp Potential: -50
(mV vs Ag/AgCl)
Flotation Gas: Nitrogen

Stage	Reagents (g/t)						Time (min)		
	CaO	R208/ 3418	MIBC	CuSO4	SEX	SO2	Grind	Cond	Froth
Grind	-	-	-				43		
Aeration									
Rougher-1	100	10/25	10	-	-	450		-	0.5
Rougher-2	-	-	-	-	-	-		-	0.5
Rougher-3	-	-	-	-	-	-		-	1
Rougher 4	-	-	-	-	-	-		-	2
Condition	y	-	-	-	-	-			
Condition	-	-	-	415	-	-		1	
Rougher	-	-	-	-	60	-			1

Metallurgical Balance

Product	Weight		Grade,%				% Recovery			
	g	%	Cu	Zn	Pb	Fe	Cu	Zn	Pb	Fe
Cu Ro Conc 1	64.4	6.62	12.1	6.94	0.74	24.4	32.2	8.4	43.7	12.3
Cu Ro Conc 2	58.5	6.02	8.50	8.07	0.37	22.3	20.6	8.9	19.9	10.2
Cu Ro Conc 3	63.5	6.52	5.66	8.21	0.24	22.5	14.9	9.8	14.0	11.2
Cu Ro Conc 4	48.9	5.02	3.46	7.73	0.17	20.5	7.0	7.1	7.6	7.9
Zn Ro Conc	35.1	3.60	2.66	39.0	0.06	13.3	3.9	25.8	1.9	3.7
Tail	702.3	72.21	0.74	3.01	0.02	9.95	21.5	39.9	12.9	54.8
Head (calc.)	972.6	100.00	2.49	5.45	0.11	13.1	100.0	100.0	100.0	100.0

Calculated Balance

Cu Ro Conc 1	64.4	6.62	12.1	6.94	0.74	24.4	32.2	8.4	43.7	12.3
Cu Ro Conc 1-2	122.9	12.64	10.4	7.48	0.56	23.4	52.8	17.3	63.6	22.5
Cu Ro Conc 1-4	235.2	24.19	7.67	7.73	0.39	22.6	74.6	34.3	85.2	41.6

Dec 11/92 Test: 61

Pulp Potential: 0
(mV vs Ag/AgCl)
Flotation Gas: Nitrogen

Stage	Reagents (g/t)						Time (min)		
	CaO	R208/ 3418	MIBC	CuSO4	SEX	SO2	Grind	Cond	Froth
Grind	-	-	-				43		
Aeration									
Rougher-1	100	10/25	10	-	-	450		-	0.5
Rougher-2	-	-	-	-	-	-		-	0.5
Rougher-3	-	-	-	-	-	-		-	1
Rougher 4	-	-	-	-	-	-		-	2
Condition	y	-	-	-	-	-			
Condition	-	-	-	415	-	-		1	
Rougher	-	-	-	-	60	-			1

Metallurgical Balance

Product	Weight		Grade,%				% Recovery			
	g	%	Cu	Zn	Pb	Fe	Cu	Zn	Pb	Fe
Cu Ro Conc 1	111.9	11.64	10.7	9.10	0.53	24.4	51.9	19.7	53.8	20.8
Cu Ro Conc 2	59.2	6.16	6.62	11.1	0.28	20.9	17.0	12.7	15.0	9.4
Cu Ro Conc 3	55.7	5.79	4.80	10.2	0.21	21.6	11.6	11.0	10.6	9.2
Cu Ro Conc 4	49.8	5.18	2.81	7.86	0.14	20.6	6.1	7.6	6.3	7.8
Zn Ro Conc	41.8	4.34	1.01	39.6	0.07	14.9	1.8	32.0	2.6	4.7
Tail	643.0	66.89	0.42	1.36	0.02	9.82	11.7	16.9	11.7	48.1
Head (calc.)	961.3	100.00	2.40	5.37	0.11	13.7	100.0	100.0	100.0	100.0

Calculated Balance

Cu Ro Conc 1	111.9	11.64	10.7	9.10	0.53	24.4	51.9	19.7	53.8	20.8
Cu Ro Conc 1-2	171.1	17.80	9.29	9.79	0.44	23.2	68.8	32.5	68.8	30.2
Cu Ro Conc 1-4	276.6	28.77	7.22	9.53	0.34	22.4	86.5	51.0	85.7	47.2