A practical study of complex sulphide separation using collectorless and nitrogen flotation.

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I. ABSTRACT

This thesis explores the potential for (1) collectorless flotation and (2) the use of nitrogen in complex sulphide flotation. Several ores from the Canadian Shield are used.

Various responses to collectorless flotation are observed. Chalcopyrite can float without collector, particularly in ores from Mattabi Mines. Galena from Mattabi ores also floats though more slowly than chalcopyrite. Galena flotation is attributed to surface oxidation while the mechanism for chalcopyrite collectorless flotation is not fully understood. A process is proposed that includes collectorless flotation and may lead to improved copper,lead separability. No collectorless flotation of pyrite and zinc-bearing minerals is observed.

Nitrogen, used as the carrier gas, promotes pyrite flotation in all ores tested. This is used to selectively remove pyrite after bulk flotation and before zinc flotation. Some zinc-bearing minerals report to the pyrite concentrate. Pyrite floated in nitrogen can, however, be depressed again in air enabling the zinc to be selectively floated after copper activation. The proposed process improves zinc rougher concentrate grades by up to 50% at similar recoveries. This is attributed to an overall reduction in the exposure of pyrite to collector and copper sulphate. The flotatic of pyrite in nitrogen is linked to the removal of dissolved oxygen. It is suggested that this may block a galvanic interaction between pyrite and sphalerite which in an oxygenated environment depresses pyrite.

II. RÉSUMÉ

Cette thèse examine le potentiel de la flottation sans collecteur et de l'utilisation de l'azote pour la flottation des sulfures complexes. On utilise plusieurs minerais du Bouclier Canadien.

La flottation sans collecteur donne des résultats qui dépendent beaucoup du minéral flotté. La chalcopyrite flotte parfois sans collecteur, surtout avec échantillons provenant des mines Mattabi. La galène des mines Mattabi flotte également sans collecteur, quoique plus lentement que la chalcopyrite. On attribue la flottation de la galène à son oxydation en surface; on ne peut toutefois pas proposer d'explication satisfaisante pour la flottation de la chalcopyrite sans collecteur. Nous prosposons un schéma de traitement qui fait appel à la flottation sans collecteur,et qui pourrait améliorer la séparation de la chalcopyrite et de la galène. On n'a pas pu flotter sans collecteur la pyrite ou les minéraux zincifères.

L'azote, lorsqu'utilisé comme gaz transporteur, favorise la flottation de la pyrite pour tous les minérais étudiés. Cette technique permet l'extraction de la pyrite, après la flottation de la chalcopyrite et de la galène, mais avant celle du zinc. Une fraction des minèraux zincifères se retrouve dans le concentré de pyrite. Cette pyrite, flottée avec l'azote, peut toutefois etre déprimeé avec l'air, pour ainsi flotter le zinc sélectivement après activation au sulfate de cuivre.

Ce procédé permet d'obtenir des concentrés de dégrossissage dont la teneur est de 50% plus élevée, à récupération équivalente. On explique cette amélioration par une réduction du contact entre la pyrite, d'une part, et le collecteur et le sulfate de cuivre, d'autre part. La flottation de la pyrite par l'azote est liée a l'élimination de l'oxygène dissout dans la pulpe, ce qui, croyons-nous, empêche l'interaction galvanique (entre la pyrite et la sphalérite) qui déprime la pyrite, en présence d'oxygène.

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1. INTRODUCTION

1.1 BACKGROUND AND THESIS OBJECTIVES.

Froth flotation has been used to concentrate sulphide minerals for 80 years and organic-based collectors such as xanthates have been used since 1925 (26,27,96).

The floatability of a sulphide mineral is dependent on the hydrophobicity of its surface. A few sulphide minerals such as molybdenite are naturally hydrophobic because of their specific lattice structures, and will float without any pre-treatment This is usually referred to as natural floatability (26). Other sulphide minerals exhibit self-induced floatability - they can be rendered hydrophobic by some form of pre-treatment (22,25-6,36,96,107-8). Most sulphides, however, need to adsorb a collector onto the mineral surface before they become hydrophobic. Electro-chemical mechanisms are believed responsible for the interaction between collector and mineral, and electro-chemical control may be the useful means of controlling mineral-collector interactions.

This thesis assesses the possible application of collectorless flotation towards achieving selective flotation of minerals from some Canadian Shield ores. Using the same ores, the thesis then considers the ability of nitrogen gas to alter the electro-chemical properties of the pulp, and thus mineral-collector interactions.

1.1.1 Collectorless (self-induced) flotation

In the last 30 years considerable progress has been made toward developing an understanding of self-induced flotation (102) Researchers, however, have generally used pure minerals and perhaps for this reason it has found little commercial application. One of the objects of this thesis is to assess the potential for collectorless flotation of a number of ores from the Canadian Shield.

1.1.2 Nitrogen flotation

In 1953, Salamy and Nixon(87) proposed an electrochemical theory of flotation and this theory has become increasingly accepted as more is learned about mineral-collector interactions (105). One of the consequences, as described by Woods(105) is the importance of pulp potential in mineral-collector interaction. Recently workers have attempted to use pulp potential to develop new approaches to achieve and control selective flotation (30,32,34,81-2,103). Because of nitrogen's chemical inertness, flotation in nitrogen could be a particularly elegant means of adjusting the pulp potential. Nitrogen has already found significant use on copper/molybdenum separation (13,73) but has not yet found any other commercial use. The effect of nitrogen on the flotation of complex sulphide ores of the Canadian Shield will be assessed in this thesis.

1.2 STRUCTURE OF THE THESIS.

This thesis includes literature reviews of collectorless flotation and the role of pulp potential and dissolved oxygen in flotation. This is followed by a description of the operating practice of the three plants from which ore was sampled for the testwork. A review of the current use of nitrogen and gases other than air in flotation is included, together with a section on the supply o ons available for nitrogen production.

The test procedures for all three ores are outlined in section three. The results section, section four, is sub-divided into the testwork on each individual ore. Further sub-divisions describe aspects of collectorless flotation and nitrogen flotation.

In section 5, the results are discussed and processes proposed which include collectorless flotation and pyrite flotation in nitrogen. With numerous mechanisms already available to explain collectorless flotation, no new mechanism is proposed in this thesis. The promotion of pyrite flotation with nitrogen is explained by elimination of a galvanic interaction between pyrite and sphalerite, which in the presence of oxygen serves to depress pyrite. An economic analysis of the use of nitrogen is included.

Sections 6 and 7 summarise the conclusions drawn and suggest directions for future work. Following the list of references, the appendices detail the results from the tests reported in the thesis.

2. GENERAL REVIEW OF BACKGROUND TO THE PROJECT.

2.1 REVIEW OF RESEARCH INTO COLLECTORLESS FLOTATION AND THE USE OF NITROGEN

2.1.1 Collectorless flotation.

Some of the earliest processes developed in flotation used the collectorless hydrophobicity of minerals. Work on Broken Hill ore in Australia, as described by Louis (57), used carbonic acid to affect self-induced flotation of sphalerite and collectorless flotation of galena was occasionally used up to 1920.

With the development of xanthates, collectorless flotation of sulphide minerals became largely forgotten. Effective collectorless flotation was considered limited to realgar, orpiment and molybdenite. Gaudin (26) explains these exceptions through their crystal lattice structure . However Sutherland and Wark (96) questioned this in 1955, by noting that galena would occasionally respond to collectorless flotation, and in doing so sparked a controversy that is still gaining momentum 30 years later. They summarized work by numerous authors who had all found that galena could float without collector, but could not agree on the mechanism and particularly whether the surface needed to be clean or oxidised. In 1960, Rey and Formanek (80) found that sphalerite would float without a collector if ground in a ceramic mill . More recently, Kocabag and Smith (49) confirmed this observation, making an in-depth study of the effect of grinding media in flotation .

Since then most of the work on collectorless flotation has concentrated on chalcopyrite. Plaksin (69) used chalcopyrite to show that hydrophobicity of sulphide minerals was possible through exposure to air. Lepetic's work (55), in 1974, showed that chalcopyrite can be floated without collector following dry grinding, achieving superior grades and recoveries than through the conventional route of wet milling and collection. Both explained their observations by suggesting that the mineral surface was adsorbing molecular oxygen, leading to a de-hydrated and hence hydrophobic surface in flotation.

An exhaustive study of collectorless flotation was performed by Finkelstein and co-workers(22) in 1975. They checked the collectorless floatability of a wide range of ores finding some chalcopyrites, pyrites, galenas, stibnites and all copper-activated sphalerites were floatable without collectors.

While that work probably convinced most researchers that effective collectorless flotation was possible, the responsible mechanism has become an object of increased interest and often considerable disagreement over the past ten years. The controversy was intensified when Heyes and Trahar (36) identified in 1977 that collectorless flotation was only possible under oxidising conditions, and Yoon (107) found, 4 years later, that chalcopyrite would float naturally following addition of a reducing agent, sodium sulphide.

While an increasing amount of evidence seems to endorse Heyes and Trahar's approach (102) that oxidising conditions are required the exact role of oxidation/reduction in collectorless flotation is still an open question.

Finkelstein and Woods agree with Heyes and Trahar (12,22,25). But while agreeeing that oxidising conditions are necessary for formation of a hydrophobic surface on the chalcopyrite there was disagreement about the specific product of oxidation that imparts this floatability. Finkelstein's work (22) concluded that elemental sulphur played no role in collectorless flotation. Gardner and Woods (25), however, proposed an oxidation reaction to explain the collectorless flotation of chalcopyrite, that included the formation of elemental sulphur:

$$CuFeS_2 + 3H_2O \rightarrow CuS + S + Fe^{3+} + 3e-$$

Later, Woods and Buckley (12), using X-ray Photoelectron Spectroscopy failed to identify elemental sulphur on the chalcopyrite surface concluding that the oxidation product was some form of copper poly-sulphide. Trahar (99) in 1983 remained consistent with the line of thinking that oxidation of the chalcopyrite surface was needed to render the mineral surface naturally floatable, though he made no conclusions as to the actual species responsible for this hydrophobicity.

Yoon's (107-8) observations in 1981 that adding sodium sulphide, a reducing agent, to the grind rendered both chalcopyrite and copper-activated sphalerite floatable, was in contrast to the other investigators. His work, on Kidd Creek ore amongst others, identified that if sodium sulphide was added to the mill, the resultant grade/recovery relationship from collectorless flotation of chalcopyrite and sphalerite was similar to that using collectors. He suggested that sodium sulphide helped dissolve superficial oxidation products leaving a clean particle surface.

More recent work by Luttrell and Yoon (58-9) illustrated again the advantage of using sodium sulphide in collectorless flotation of chalcopyrite. They concluded that freshly ground chalcopyrite would not float naturally under reducing conditions and that oxidised chalcopyrite would also not float naturally. Chalcopyrite, however, treated with sodium sulphide under oxidising conditions would float naturally.

In 1984, Heyes and Trahar (37) concluded that pyrite could also be floated following oxidation and treatment with sodium sulphide. They concluded that sodium sulphide causes sulphur to form on the pyrite surface and this sulphur is responsible for the minerals hydrophobicity and natural flotation characteristics.

Only a thin sulphur layer can, however, be formed on chalcopyrite because of the relative instability of elemental sulphur at common flotation potentials. This indicates that elemental sulphur formation is not the mechanism behind natural flotation of chalcopyrite. Nevertheless, Walker and co-workers (102) observed that chalcopyrite could be made floatable by electrodeposition of sulphur at potentials well below those permitting the oxidation of the mineral. In short, the mechanism behind the collectorless flotation of chalcopyrite remains unclear (102).

The contrasting theories behind the collectorless flotation of chalcopyrite may illustrate the problem of trying to explain it on a pure mineral basis. Mineralogical texts describe that chalcopyrite can contain any of eleven elements replacing the iron, copper and sulphur (16). Furthermore the copper:iron:sulphur ratio can vary (one single specimen gave copper contents varying from 25.8% to 30.7%), and measurement of X-ray Absorption edges have shown that the copper can exist in the +1 or the +2 states, the iron then existing in the +3 and the +2 states respectively. Analysis through cryoscopic and electrolytic methods have also shown that both metals can be divalent (16,63,74). Such variations in the mineral must lead to different reactions and different reaction mechanisms.

The mechanism behind the collectorless flotation of pyrite and galena seems to be more clearly understood. Rao and Finch (77) showed that, following sufficient oxidation, pyrite from Brunswick Mining ore can float without collector, albeit weakly, and this could be used to improve subsequent zinc-pyrite selectivity. Voltammetric data suggests the initial product from oxidation of the pyrite and galena surfaces, is the polysulphide ion, though as further oxidation occurs elemental sulphur forms on the surface (37). The actual species present on the mineral surface is probably related to the degree of oxidation and the relative kinetics of the reactions involved, but with sufficient oxidation a relatively thick sulphur layer can be formed on the surfaces of pyrite and galena.

This is particularly relevant as Walker and Richardson (102) observed that the hydrophobicity of the mineral surface is related to the thickness of the elemental sulphur formed on the surface. Such conditions seem to have occurred on a number of the pyrite-rich gold tailings dumps in South Africa which often respond readily to collectorless flotation (67).

While researchers do seem to agree on a mechanism behind the collectorless flotation of pyrite and galena, variations for mineralogical reasons are still possible (galena, for instance can have a eutectic intergrowth of up to 30% iron sulphide(16)).

This thesis will check the effect of collectorless flotation on some Canadian ores, and will highlight the variations in response to collectorless flotation possible in some similar pyritic ores of the Canadian Shield.

2.1.2 ROLE FOR NITROGEN: THE ELECTROCHEMICAL THEORY OF FLOTATION.

The use of nitrogen in flotation was conceived as a logical progression from the electrochemical-based theory developed over the last thirty years to explain mineral-collector interaction.

Only in recent years has significant progress been made in the understanding of collector attachment to minerals. While a basic understanding of the role of collectors was available by the 1950s, little was known about the mechanism of collector-mineral attachment (26-9).

In the 1950s it was largely accepted that collector-mineral reactions largely involved ion adsorption (26) through a relatively simple series of well-defined reactions, although other theories had been suggested as outlined by Gaudin and more recently Leja (26,54).

In 1952, Salamy and Nixon (87) proposed an electrochemical mechanism involving the simultaneous anodic oxidation of collector and cathodic reduction of oxygen, on the mineral surface. This has become increasingly accepted as more is learned about the mechanism of the various mineral sulphide-collector-oxygen systems, and of the variety of surface species produced from the reactions (105).

Sulphide minerals are semi-conductors and can thus act either as a source of electrons or an acceptor of electrons. They act as the former in the reaction with the collector, and the extra electrons are conducted away and react with oxygen (see Figure

2.1). The reaction with the collector (the anodic oxidation reaction resulting in spare electrons) may be of two types:

formation of dixanthogen:

$$2ROCS_2^{2-} \rightarrow (ROCS2)_2 + 2e- \ldots\ldots \langle 1\rangle$$

or reaction (chemisorption) with the mineral itself:

$$PbS + 2ROCS_2^{2-} \rightarrow Pb(ROCS_2)_2 + S + 2e- \ldots\ldots \langle 2\rangle$$

The surplus electrons would then reduce oxygen, effectively simultaneously, in the following cathodic reduction reaction:

$$1/2O_2 + 2H+ + 2e- \rightarrow H_2O \ldots\ldots \langle 3\rangle$$

Which of the two anodic reactions predominates depends on the mineral, the collector and the pulp potential. Investigations by Goold and co-workers (32) in the early 1970s led to a correlation between minerals, collectors, and potentials at which the reactions start to occur (rest potentials) and surface products, as shown in Table 2.1. The table shows the effect of the rest potential on the final reaction product. If the rest potential is high (above the reversible potential for the oxidation of xanthate to dixanthogen) then the product is dixanthogen. If it is lower than the reversible potential, then the product is the metal xanthate. The one exception is covellite and xanthate. This is explained in terms of the reaction of dissolved cuprous ions from the mineral surface with the xanthate (32,105).

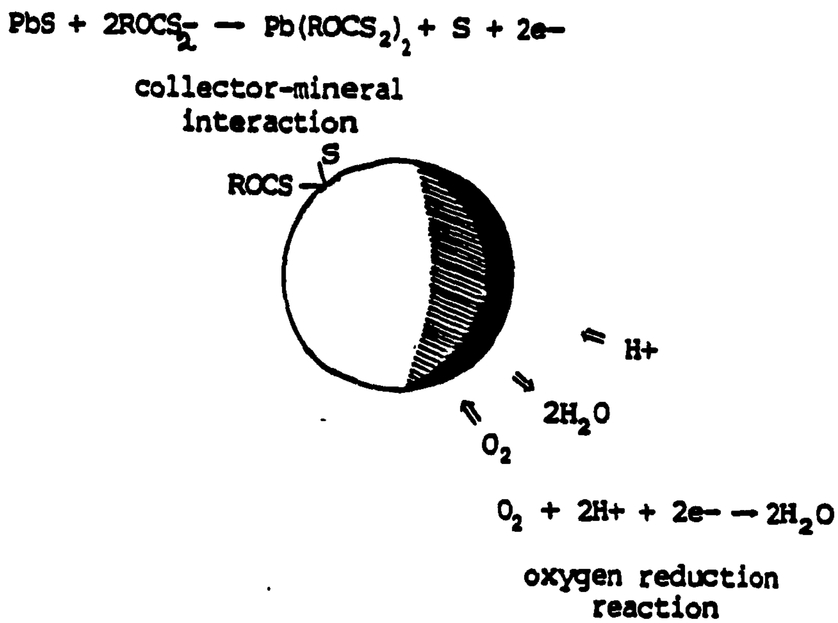


FIGURE 2.1 - Principle of collector oxidation and oxygen reduction on galena surface.

TABLE 2.1 : The reaction product and starting (rest) potential of the anodic reaction of various mineral-collector combinations. (105)

mineral	collector	rest potential vs S.H.E.	product
pyrite	KEX	0.22V	dixanthogen
arsenopyrite	KEX	0.22V	dixanthogen
pyrrhotite	KEX	0.21V	dixanthogen
chalcopyrite	KEX	0.14V	dixanthogen
rev. potential for oxidation to dixanthogen - 0.13V			
covellite	KEX	0.05V	dixanthogen
bornite	KEX	0.06V	metal xanthate
galena	KEX	0.06V	metal xanthate
pyrite	DtC	0.475V	disulphide
rev. potential for oxidation to disulphide - 0.176V			
covellite	DtC	0.115V	metal DtC
chalcopyrite	DtC	0.095V	metal DtC
galena	DtC	-0.035V	metal DtC
bornite	DtC	-0.045V	metal DtC
chalcocite	DtC	-0.155V	metal DtC

note: KEX - Potassium ethyl xanthate (0.000625M at pH 7)

: DtC - Sodium diethyl dithiocarbamate (100.ppm at pH 8)

Generalisations are always dangerous. Gaudin (28) identified metal xanthates as well as dixanthogen on the surface of pyrite and it is likely that in all cases both reactions occur, although one will tend to predominate over the other. Most of the evidence in the past twenty years has suggested that dixanthogen is the active species in pyrite flotation (21,22,61).

Pyrite floats in air most effectively at potentials above that of dixanthogen formation (105). This suggests that by maintaining the pulp potential below the rest potential for dixanthogen formation on pyrite, or preferably below the reversible potential for xanthate oxidation to dixanthogen, pyrite could be depressed. This is an example of electrochemical control of flotation which has commanded much attention at the U.S. Bureau of Mines in recent years (30,81,82,103).

Investigators at the U.S.B.M. have shown that, with single minerals, the flotation of chalcopyrite, pyrite, bornite and chalcocite is strongly dependent on pulp potential (82). When mixed beds are used interactions between the minerals tend to distort the result. For example, in a chalcocite-pyrite mixture , pyrite is floated at different pulp potentials than in the case of pyrite alone possibly through activation by copper ions dissolved from the chalcocite surface (Figure 2.2)(30).

While the idea of selective flotation through control of the pulp potential has possibilities, external control of the potential through contact with electrodes, as being attempted at the U.S.B.M., pose severe practical difficulties on a large scale.

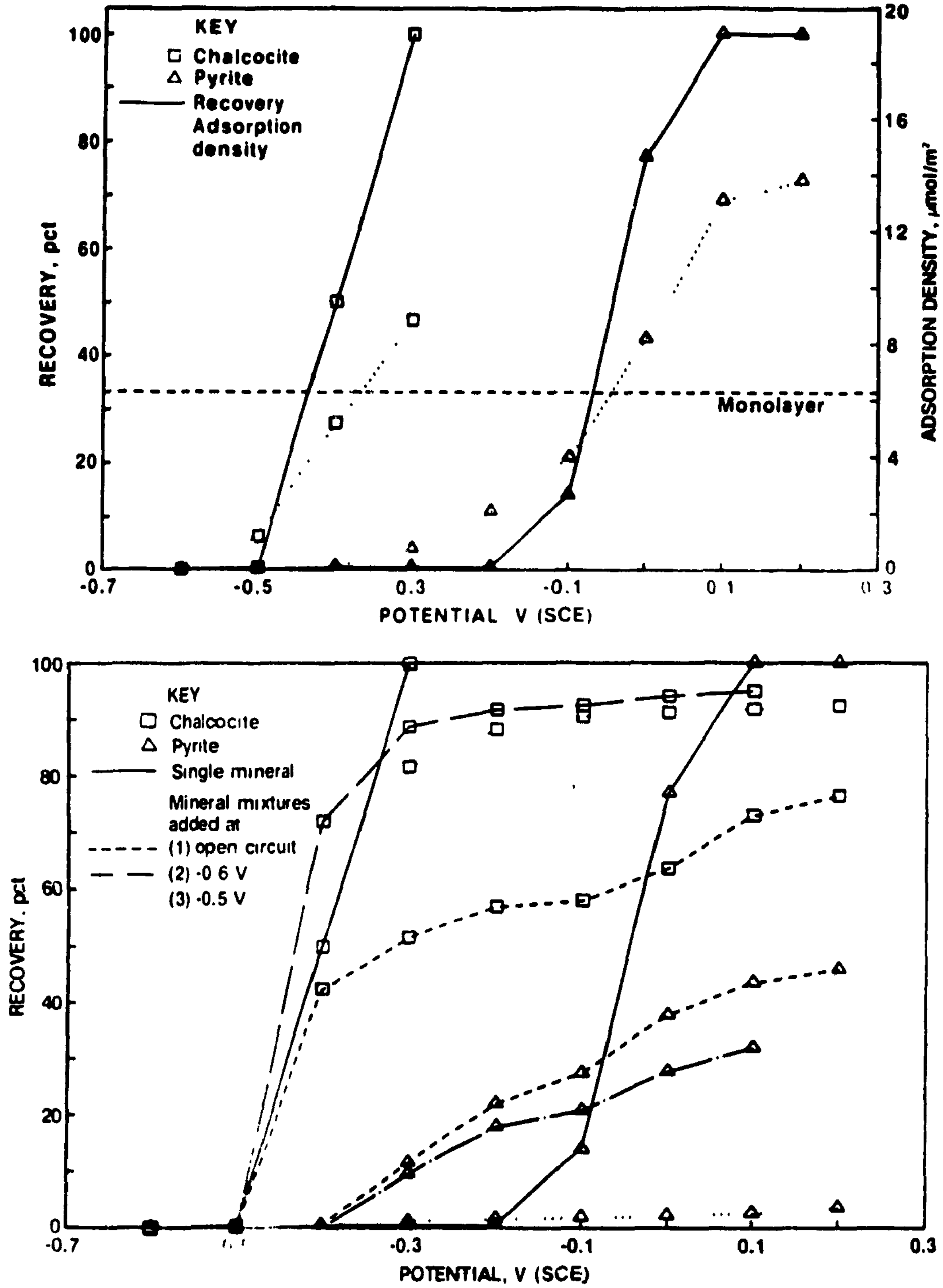


FIGURE 2.2 - Collector adsorption densities and flotation recoveries of pyrite and chalcocite as single minerals and combined.

The first graph shows that if flotation was to take place at -0.2 to -0.3 volts, chalcocite would float and pyrite remain depressed, based on their floatabilities as single minerals. The second graph shows how the flotation recoveries of the minerals become less potential dependent when added together.

Chemical control of potential has possibilities (and may already be practiced albeit unknowingly). Outokumpu have run pilot tests using control of pulp potentials, as against pH. This testwork used sulphuric acid for potential control. It resulted in savings in reagent costs (particularly xanthate and frother where up to 50% savings were reported), and an improvement in economic returns from concentrate production. So far tests have been run on copper/nickel ores and gold ores. Whether the technique can be applied to more complex ores such as the pyritic copper/lead/zinc ores of the Canadian Shield remains to be seen(34).

Development of improved process control methods is only one consequence of recent progress in flotation electrochemistry. Many reagents used in current circuits may activate or depress by changing the pulp potential. If this is the case then a reagent that adjusts the pulp potential without interfering with any other aspect of flotation chemistry could be extremely useful.

Nitrogen may be such a reagent. Nitrogen gas is currently used in the flotation separation of molybdenite from chalcopyrite (see Section 2.3)(73). Nitrogen gas as the gas phase in flotation would reduce the pulp potential. It is also an inert gas and should thus not interfere directly with any chemical mechanisms. In, for example, pyritic ores containing zinc, zinc-pyrite selectivity could be improved by lowering the potential below the rest potential for pyrite flotation (76-7). One of the objects of this thesis is to extend this idea one step further, and incorporate nitrogen into a complex copper/lead/zinc flowsheet using a currently processed ore.

Nitrogen will also purge dissolved oxygen out of the pulp. This may reduce flotation through blocking Reaction 3. However the role of oxygen in a flotation pulp is not fully understood and its removal could affect other mechanisms which contribute to mineral surface hydrophobicity. One such mechanism is galvanic interaction between different minerals, as described by Kocabag and Smith in 1985 (46). Figure 2.3 illustrates the mechanism they proposed for pyrite, a particularly noble sulphide, and another sulphide mineral. The two results relevant to flotation are:

- the production of elemental sulphur on the mineral acting as the anode (and possible resultant collectorless flotation), and,
- the formation of hydrophilic ferrous hydroxide on the pyrite surface, making it less floatable.

Dissolved oxygen is fundamental to such a mechanism so use of nitrogen could block it by removing the oxygen. This would render the pyrite more floatable, counter-acting the effect of inhibited collector-mineral interaction.

Further consideration will be given to the possible role of galvanic interactions in depressing pyrite in the discussion section (Section 5.2.1).

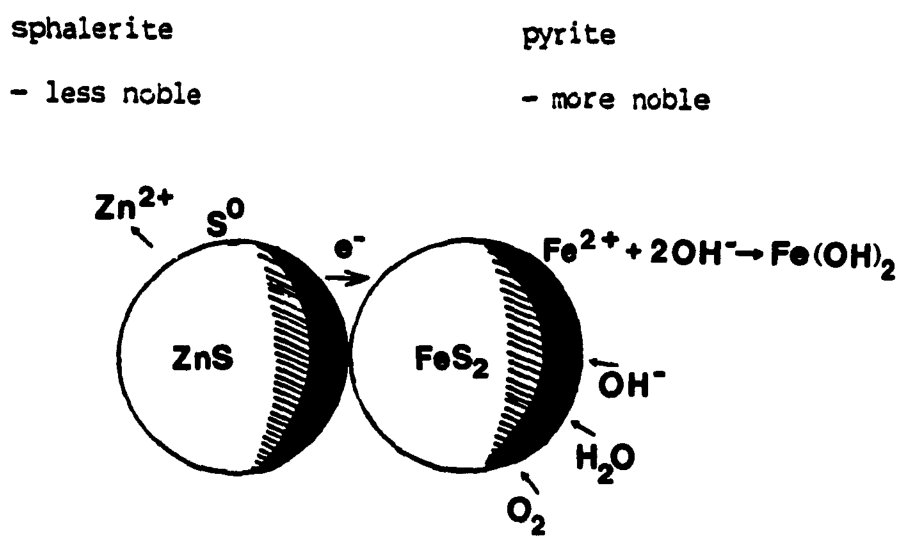


FIGURE 2.3 - Proposed galvanic interaction between pyrite and sphalerite, leading to an oxidised sphalerite surface and a hydrophilic pyrite surface.

2.2 REVIEW OF ORE MINERALOGY AND CURRENT METALLURGY AT THREE CANADIAN OPERATIONS.

2.2.1 Brunswick Mining and Smelting (Figure 2.4).

The Brunswick #12 ore deposit is one of the largest complex sulphide deposits in the Canadian Shield (93). It contains 100 million tonnes of complex sulphide ore, averaging 9.0% zinc, 3.5% lead, 0.3% copper and 98 grams per tonne silver.

The deposit, situated 27 km south west of Bathurst, N.B. is composed of sedimentary and volcanic rocks which were metamorphised and deformed during Ordovician and Devonian times (53,86,95). The ore is 80% sulphides, of which almost 60% is pyrite. The principal zinc minerals are sphalerite (zinc sulphide, low in iron) and marmatite (zinc sulphide, high in iron) , lead is mineralised as galena (lead sulphide), copper as chalcopyrite (copper,iron sulphide) and silver as tetrahedrite (copper,silver,antimony)sulphide and other sulphide minerals. Some of the other minerals occurring are pyrrhotite, arsenopyrite, marcasite, boulangerite, stannite, cassiterite and pyrargyrite.

While high-grade bands contain relatively coarse-grained values (100-1000μm), low grade bands are much more finely disseminated. The economic optimum grind size is currently 65%, -37μm for primary grinding, though it is significantly finer in the regrind circuits.

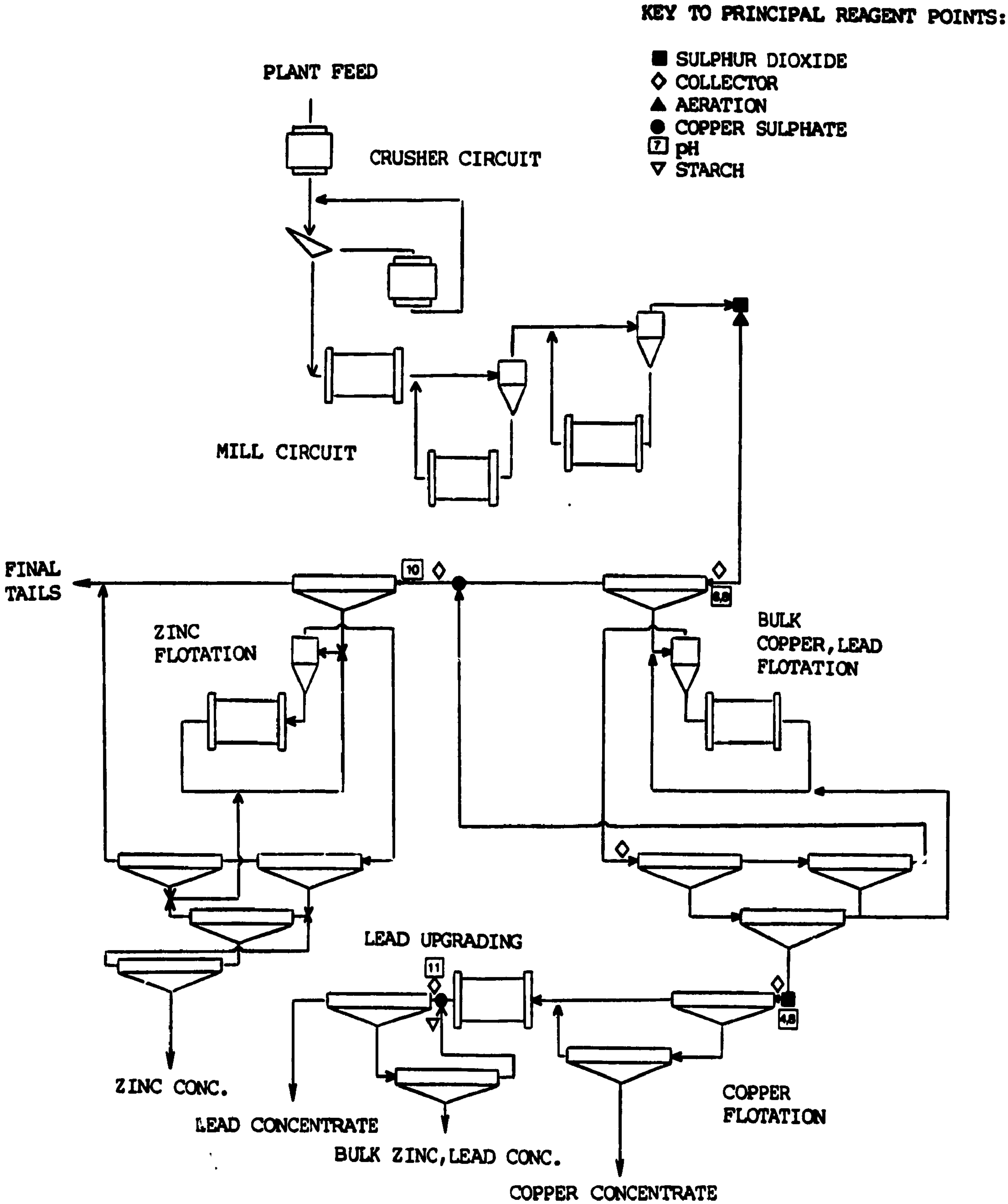


FIGURE 2.4 - Brunswick Mining general plant flowsheet.

Mine production has been entirely from underground since 1980. The mine uses a mechanised cut-and-fill method which replaced open stope mining in 1971. Ore is hoisted using 15 ton skips through numbers 2 and 3 shafts from three primary crushing units, roughly 1000 m underground. The mine currently extracts 10,250 tonnes of run-of-mine ore daily (68).

The ore is crushed to minus 15cm underground using 2 Traylor type-H jaw crushers and one Allis-Chalmers gyratory crusher. Once on the surface it is crushed further, to minus 1.2cm in each of two plants. A secondary 1.7m Symons standard cone crusher operates in open circuit, the crusher product sized on a 1.2cm vibrating screen. Oversize is crushed in a tertiary 1.7m shorthead cone crusher, in closed circuit with the screen.

Brunswick Mining has three grinding lines (17). Numbers 1 and 2 (2900 tonnes/day each) receive ore from crusher plant number one. They consist of a 3.2m by 4.3m primary rod mill with 3.2m by 4.0m secondary and tertiary ball mills. Number 3 grinding section (4200 tonnes/day) receives ore from number 2 crusher plant and consists of a 3.8m by 4.9m primary rod mill with 3.8m by 4.6m secondary and tertiary ball mills. 76mm rods (and 100mm in line 3) are used for primary rod milling, and 32mm Manmet slugs are used for ball milling.

Two stage cyclones size the mill products. The primary cyclones are 25cm diameter Krebs cyclones. They classify the rod mill discharge and are in closed circuit with the secondary ball mill. The secondary cyclones, 15cm Krebs cyclones, are in closed circuit with the tertiairy ball mill.

Soda ash is added to maintain a pH of 8.8 in the grinding circuit together with 150 g/tonne sulphur dioxide. The role of sulphur dioxide is to depress sphalerite and pyrite in the bulk flotation, although its exact action is not known. Results from work at Brunswick Mining by Hill appear to confirm this philosophy (38). Theoretical aspects of sulphur dioxide depression will be considered at a later stage (Section 2.3).

The secondary cyclone overflow is fed to an aeration stage with 25 minute retention time. Aeration further depresses pyrite flotation. After flotation two collectors are added consisting of (1) plant xanthate containing sodium isopropyl xanthate (80%) and amyl xanthate (20%) at 30 g/tonne and (2) Cyanamid AEROFLOAT dithiophosphate (241) added at 20 g/tonne.

Bulk flotation is carried out using 8 m3 Outokumpu cells, producing a concentrate containing 18% combined lead and copper. The bulk rougher concentrate is then re-ground to 81% minus 38 um in a 3.2m x 4.0m ball mill.

Two stages of cleaning produce a concentrate containing 29% lead, 2.5% copper and 700g/tonne silver. The bulk cleaner circuit is open, the thickened tails from each stage combining with the bulk scavenger tails to form the zinc flotation feed.

The bulk cleaner concentrate is treated with activated carbon to remove dissolved organics (e.g excess collector), though the carbon may also remove some of the collector coating from the galena surface (38). It is also treated with starch which helps to depress the galena. Sulphur dioxide is then added to the pulp which further depresses the galena, and maintains a pH of 4.8 during conditioning and copper flotation.

A copper concentrate is floated using 10-20 g/tonne of an alkyl-alkyl thionocarbamate (Cyanamid AERO 3894) and cleaned three times. The final copper concentrate contains 22% copper, 6% lead and 3000 g/tonne silver.

Significant quantities of marmatite float with the copper/lead concentrate. Marmatite has been found to be very finely disseminated in galena so Brunswick Mining are forced to produce a low-grade zinc concentrate from the lead concentrate (35,72).

The copper flotation circuit tail is reground to 85% minus 38μm in a 3.7m by 4.6m ball mill before being fed to the zinc,lead separation circuit. The ball mill discharge is heated to 70 deg C using steam injected into the pulp, to destroy any residual collector or starch from the copper flotation circuit. The pulp is then cooled to 35 deg C by decantation and repulping with cool water.

Lime is added to pH 10.8 and copper sulphate added to activate the marmatite (1000 g/tonne). A bulk (predominantly zinc) rougher concentrate is then floated with xanthate and cleaned twice, producing a final bulk zinc/lead concentrate containing 34% zinc and 18% lead. The tailings from this circuit assaying 35% lead and 5% zinc is the lead final concentrate.

The zinc circuit is conditioned with 650 g/tonne copper sulphate at pH 10.5 using lime for pH adjustment. Further conditioning with plant xanthate (30 g/tonne) and cyanamid's AERO 3894 (20 g/tonne) leads to the flotation of a zinc rougher concentrate (34% Zn), from 32 Outokumpu 8 m^3 cells.

The zinc rougher concentrate is reground in a 3.8m by 4.9m ball mill to 95%, -38µm and floated three times in a closed zinc cleaner circuit. The final concentrate contains 52% zinc.

The zinc rougher tail was formerly directed to a scavenger, or secondary zinc flotation circuit. This used to produce a low-grade zinc concentrate that was up-graded using reverse flotation of pyrite from the zinc. The assay of this secondary zinc concentrate was 48% zinc, and it was combined with the primary zinc circuit concentrate. This circuit is, however, no longer used.

In summary, flotation problems are a combination of difficult chemistry increased by the fine grind and finely disseminated low-grade bands in the ore. Some of the features of the circuit as a result of these factors are:

* Zinc floats to the bulk circuit, necessitating the production of a zinc concentrate from the lead/copper bulk concentrate.
* Excessive pyrite floats to the zinc concentrate, resulting in low zinc grade in the rougher concentrate and increased reliance on the zinc cleaner circuit.

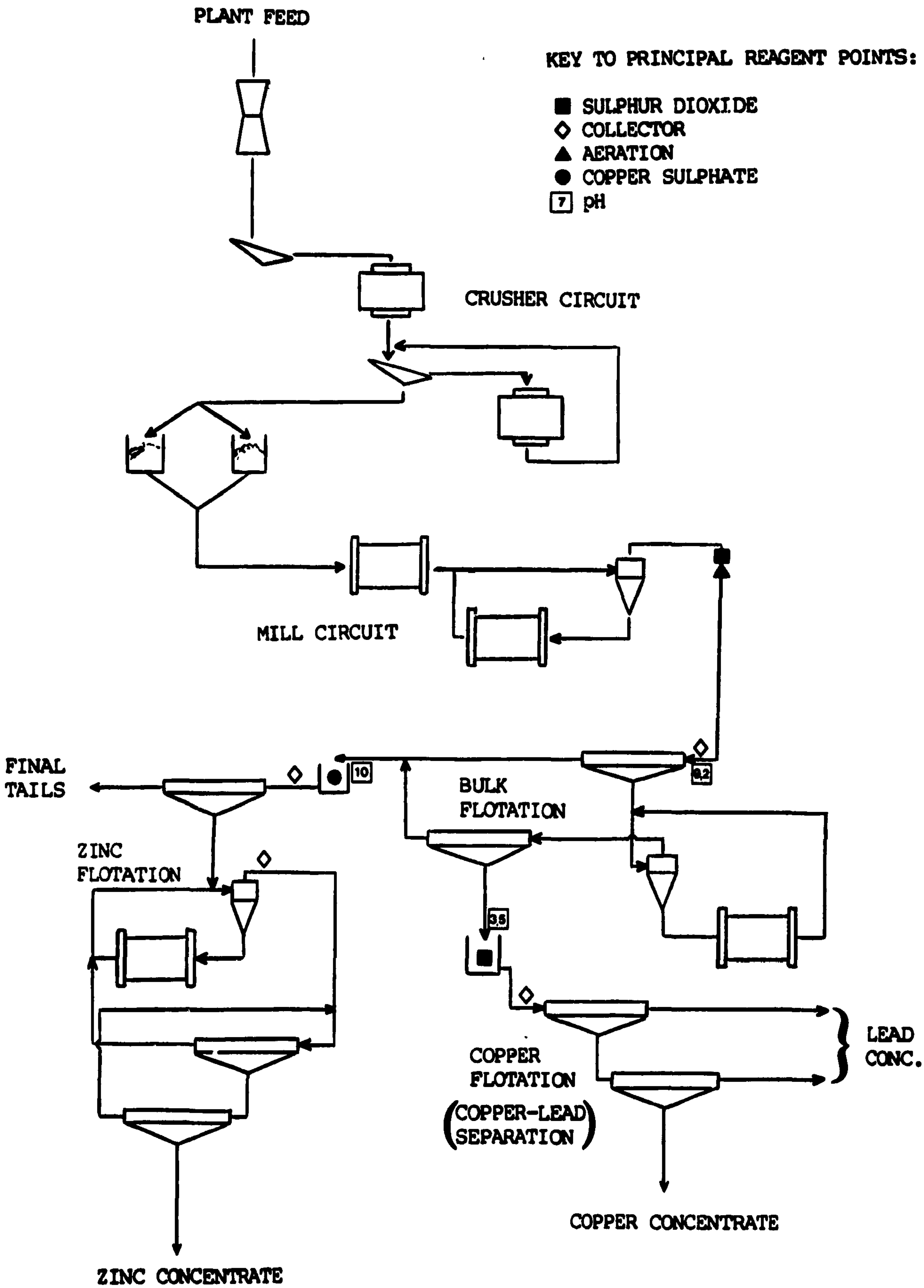


FIGURE 2.5 - Mattabi Mines general plant flowsheet.

2.2.2 Mattabi Mines Ltd, Milling operations (Figure 2.5-4,65).

The mill, set on the shore of Sturgeon Lake 90 km north east of Ignace in Ontario, treats 3000 tonnes per day of pyritic copper, lead, zinc, silver ore mined underground.

The ore treated through the mill when this testwork was performed, was mined from the Mattabi (80%) and Lyon Lake (20%) deposits. Typical head grades are 11% zinc, 0.65% copper, 0.6% lead and 32% iron. The ore also contains approximately 100 g/tonne of silver. The principal valuable minerals are sphalerite, chalcopyrite, galena and tetrahedrite. The most abundant gangue mineral is pyrite, which comprises 70% of the ore. In all, sulphides comprise between 85 and 90% of the ore.

The ore is, by Canadian Shield standards, relatively coarse-grained. The economic optimum grind size being 75% -74µm from primary and secondary milling though intermediate products are ground considerably finer in the bulk copper/lead and zinc regrind circuits. The flowsheet is summarised by Figure 2.5.

The ores from the two mines are batch-crushed and stored separately for later blending. Primary crushing is performed underground by a Bowborough jaw crusher for Lyon Lake ore and through a gyratory crusher on the surface for the Mattabi ore. All ore currently passes through the gyratory crusher, to aid material handling. Both ores are stockpiled separately after primary crushing in an ore storage building with a live capacity of 8000 tonnes.

The mill uses a 33cm x 2.13m Allis-Chalmers hydrocone crusher for secondary crushing to -1.9cm. A 1.83m x 4.88m double-deck screen sizes the primary crusher product, the oversize feeding the secondary crusher.

A larger (2.44m x 6.10m) single deck screen sizes the secondary crusher product. This is in closed circuit with an Allis-Chalmers 12.7cm x 2.13m hydrocone tertiary crusher. Product from the crusher plant is stored in two 4000 tonnes fine ore bins. Number 1 bin stores Mattabi ore and number 2 bin stores Lyon Lake ore. Ore fed into the grinding circuit is monitored by a Merrick Model E-315 weightometer.

The current grinding circuit consists of primary and secondary ball milling. The primary mill is a Dominion Engineering 3.05m x 4.88m ball mill, and is charged with 7.62cm forged steel balls. Primary mill discharge comprises a significant amount of coarse rock, predominantly rhyolite. A 1.27cm trommel screens off this coarse material which is barren in base metal sulphides. This is used for road bedding.

The trommel undersize is classified in four 38 cm Krebs primary cyclones. Cyclone underflow feeds a 3.05m x 4.88m Allis-Chalmers secondary ball mill using 2.54cm x 1.27cm "Norcast" slugs. Coarse rhyolite is again screened off using a 1.11cm trommel. Screen undersize is circulated back to the primary cyclone feed. Primary cyclone overflow is directed to the flotation circuit.

The cyclone overflow is aerated and treated with sulphur dioxide to depress the pyrite and the sphalerite. The pH is adjusted to 9-9.5 using soda ash. Collector composed of sodium ethyl xanthate (Cyanamid 325 - 2.5 g/tonne) and aryl dithiophosphoric acid (Cyanamid 241 - 2.5 g/tonne) is added to float the copper, lead and silver.

A bulk concentrate is floated in 16 Agitair 1.4 m^3 cells and includes a middlings product, which is circulated back to the conditioner in the bulk float feed. The copper, lead rougher concentrate contains roughly 25% copper and lead combined. This is reground in a Marcy 1.52m x 2.44m ball mill to 95%, -74µm and refloated using eight 1.34 m^3 flotation cells to a combined copper, lead grade of 35%. Methyl isobutyl carbinol (MIBC) is used as the frother in the copper/lead circuit.

Starch (wheat dextrine) is added to the copper, lead bulk concentrate together with a small amount of activated carbon to remove residual reagents in solution. Steam is then injected into the pulp, raising the pulp temperature to 50 deg C which strips the adsorbed collector off the mineral surfaces. The pulp is then slowly cooled to 30 deg C and sulphur dioxide added to depress the galena.

A diisoamyl dithiophosphate (Cyanamid 3501) is then added to the pulp and a copper concentrate floated using 8 Denver (1.34 m^3) cells. This is then cleaned using more sulphur dioxide at pH 3.5 and further flotation in 8 Denver 1.34 m^3 cells. The final copper concentrate contains 24% copper and 12% lead. The tails from copper, lead separation and copper cleaning are combined and directed to the lead concentrate thickener. This final lead concentrate contains 27% lead, 11% zinc and 5% copper.

In contrast to the separation problems encountered in the flotation of copper and lead, the production of a zinc concentrate is relatively straightforward. Copper sulphate (550 g/tonne) is added at pH 10-10.5 (adjusted using hydrated lime), activating the sphalerite. A mix of collectors is added: a thionocarbamate (Minerec 2030) and sodium ethyl xanthate (Cyanamid, aerofloat 325) at a combined rate of 38 g/tonne.

Eighteen Agitair 1.4 m^3 cells are used for zinc rougher flotation, producing a concentrate that is directed to a regrind circuit and a middlings that is recirculated to the zinc conditioner. The zinc rougher concentrate contains 43% zinc and is reground in a 2.13m x 3.35m Allis Chalmers ball mill, in closed circuit with 6 Krebs cyclones to 95%,-74μm . This is now cleaned using 16 Agitair 1.4 m^3 cells (middlings and tails are redirected to zinc cleaner feed and zinc rougher feed respectively). The cleaner concentrate is re-cleaned using 8 Denver 1.34 m^3 cells in closed circuit, producing a final concentrate of 53% zinc.

Overall plant recoveries are 91% of the zinc, 75% of the lead and 50% of the copper. The main metallurgical problem lies with copper/lead separation and zinc depression in the bulk circuit, though the latter problem has only become significant since a greater proportion of the ore has originated from the Lyon Lake deposit (65).

Zinc flotation is relatively straightforward, rougher grades being roughly 45% zinc. Consequently not much is demanded of the cleaner circuit making it relatively easy to operate.

2.2.3 Kidd Creek Mines "D" Division (Figure 2.6-2,84)

The Kidd Creek Concentrator is located 28 km east of Timmins, Ontario. It treats two types of ore known as A ore (a copper-zinc ore) and C ore (a copper-lead-zinc ore). The total tonnage treated is 12,370 tonnes/day. This thesis is concerned with the C-type ore, which is treated separately from the A-type ore. The throughput of "C" ore is 3100 tonnes/day.

The ore is mined from a massive pyritic deposit, which contains 9% zinc in the form of sphalerite, 0.9% lead as galena, 0.6% copper as chalcopyrite and 230 g/tonne silver, largely as native silver. The chief gangue mineral is pyrite with pyrrhotite occasionally occurring. The chief non-sulphide gangue is rhyolite though graphite may also occur.

Primary crushing at the mine-site reduces the run-of-mine ore to minus 150 mm. This is further crushed in a 1000 tonne/hour fine crushing plant, to minus 16 mm. Primary crusher product is screened on a 50 mm square hole rubber deck screen, the oversize feeding the secondary crusher. Two Allis-Chalmers hydrocone crushers perform the secondary crushing, these being set to 32 mm. Undersize is screened on a 19 mm steel rod-deck screen. Oversize from the rod-deck screen is combined with oversize from the crusher product screens and recycled to the tertiary crushers, three Allis-Chalmers hydrocone crushers set at 13 mm. Crusher discharge is sized using two 40 mm by 23 mm slotted screens.

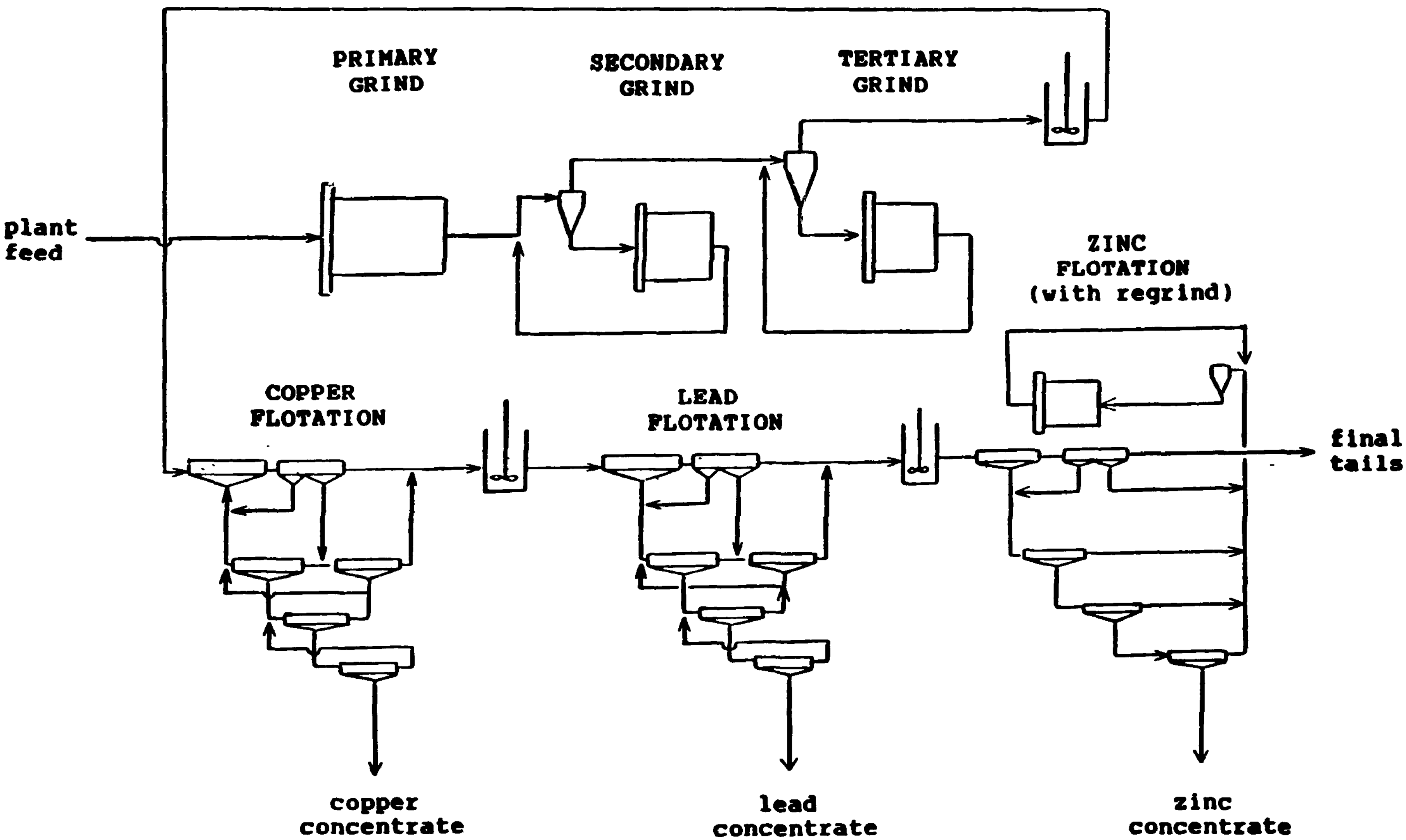


FIGURE 2.6 : Kidd Creek Mines "D" Division general flowsheet.

The grinding circuit consists of an Allis-Chalmers 3.2m by 4.9m rod mill and 3.7m by 5.5m Allis-Chalmers secondary and tertiary ball mills. The rod mill is lined with Noranda Ni-hard wave liners and Domite chrome-moly end liners and uses forged steel rods. The ball mills are rubber lined and use forged steel balls. The primary mill discharge is classified in 38cm Krebs cyclones, secondary and tertiary mill discharges being classified by 25 cm Krebs cyclones. These cyclones produce a flotation circuit feed at 73 percent minus 45 microns. Sometimes incorporated into the grinding circuit is a silver flotation circuit, which treats a 20 tonnes per hour bleed from the secondary mill discharge. Four Outokumpu 1.5 m^3 cells are used for rougher flotation and six Wemco-Fagergren 0.09 m^3 cells are used as cleaners. Cyanamids R208 collector is used to collect the silver, MIBC being used as a frother.

The grinding circuit product is treated with 500 g/tonne sulphur dioxide (without aeration). A copper concentrate is then floated at pH 8.5 (adjusted using lime) with 60 g/tonne Cyanamid R317 and/or R208 collectors. MIBC is used as a frother. Rougher concentrate is cleaned three times, at pH 6.5 (dropped using sulphur acid to aid galena depression). Denver and Wemco cells with a total capacity of 55 m^3 float the rougher concentrate, cleaning is performed in Denver cells with a capacity of 16 m^3. The final copper concentrate is relatively low-grade, being typically 17% copper.

Following copper flotation, 48 g/tonne of xanthate collectors (R208 and R317) are added to float the lead. The cell configuration is the same as the copper circuit, although Denver cells with 23 m^3 capacity are used for cleaners and no Denver cells are used for the roughing stage. Flotation is performed at pH 8.2, yielding a final lead concentrate containing 12% lead and 10% copper.

650 g/tonne of copper sulphate is added to the lead circuit tails and is conditioned for approximately 8 minutes at pH 10. Xanthate is added during copper conditioning at approximately 60 g/tonne. Zinc roughing and scavenging uses three banks of Wemco 4.2 m^3 cells, each bank with 14 cells. Rougher concentrate is cleaned three times at pH 11 using Wemco 4.2 m^3 cells. The tails from each cleaner stage are combined with a scavenger concentrate and reground in a 2.4 m by 3.7 m Allis-Chalmers regrind ball mill. This is in closed circuit with 15 cm Krebs cyclones. Cyclone overflow is retreated with copper sulphate, collector and frother and added mid-way down the rougher circuit. The final concentrate assays 50% zinc.

In recent years the zinc concentrate has been subjected to a pyrite reverse float, whereby significant quantities of sulphur dioxide have been added to the concentrate (roughly 2000 g/tonne of concentrate) dropping the pH to 4.0. This is conditioned for 15 minutes and cyanamid 3418 collector added. A silver-rich pyrite concentrate is floated and cleaned three times. The pyrite circuit tails now assay 55% Zn, the pyrite concentrate is added to the copper concentrate increasing the silver assay of the latter.

The success of the pyrite float is indicative of the poor zinc-pyrite selectivity achieved in the zinc circuit. Poor copper-lead selectivity is also a feature of the circuit, this particularly affecting lead grade and recovery. The low feed grade of the lead, together with the low silver content and economic value of the lead concentrate reduces the economic significance of the lead circuit. Much of the attention of research into the plant is therefore focused on the zinc circuit.

2.3 THE USE OF GASES OTHER THAN AIR IN FLOTATION

While air is probably used as the flotation gas in more than 99% of the plants world-wide, gases other than air played a significant role in the early development of flotation. Some of the earliest recorded work in flotation development was performed by the Bessel Brothers in the 1870s and 1880s. They used steam and carbon dioxide as the gaseous phases in flotation. The work by Potter in Australia made use of reactions between acid and carbonate minerals to form carbonic acid, and this became the carrier gas in the flotation process (57).

The application and potential application of some gases is described in this section.

2.3.1 Nitrogen

The industrial use of nitrogen in flotation is currently limited to copper/molybdenum separation. While the use of nitrogen (as patented by Delaney in 1972,(18) is not to control mineral collector interaction a brief description of its use in copper/molybdenum flotation metallurgy is still useful.

A copper/molybdenum bulk concentrate is normally floated using conventional xanthate and dithiophosphate collectors (13). However the subsequent separation of molybdenite by flotation from chalcopyrite takes advantage of molybdenite's natural hydrophobicity. So, for effective copper/molybdenum separation, the collector coating must be removed from the chalcopyrite.

Acidification and conditioning alone fails to remove all this coating so a strong reducing agent is added. In the case of Gibraltar Mines (British Columbia) sodium hydrosulphide (NaHS) is used for this purpose (although Nokes reagent is also commonly used). This, like any other strong reducing agent is readily oxidised by dissolved oxygen during flotation and as a result over 8,000 g/tonne of sodium hydrosulphide is used, considerably more than the 25 g/tonne that, according to stochiometric calculations, is needed (13).

The idea of using nitrogen appears to have derived from work by Soviet investigators on using various gases, including steam in copper/molybdenum separation. The gas lowers consumption of the reducing reagent and so reduces reagent cost. Nitrogen may find a use in flotation whenever reducing conditions are beneficial; and it could theoretically reduce the consumption of other reagents such as sodium cyanide and sodium hydrosulphite.

Savings upon using nitrogen are often considerable. Podobnik and Shirley reported that the savings in Nokes reagent were over 60% (73). At Gibraltar Mines, the drop in sodium hydrosulphide consumption has been more than 75%, saving over a million dollars per year. In the Soviet Union the use of nitrogen has been reported to have cut reagent costs in half (89).

While Shirley (1980) noted that nitrogen gas could only be used beneficially in copper flotation, the increasing use of flotation columns and the resultant reduction in gas volumes used in flotation may open new economic avenues for the use of nitrogen.

Furthermore, Soviet investigators have recently established that nitrogen effectiveness is related to pulp temperature, temperature control being one way for further optimization in the use of nitrogen (89).

Outside copper/molybdenum separation, the potential value of nitrogen as a carrier gas in flotation has never been assessed. Its role as a pyrite depressant in sphalerite/pyrite separation has been proposed by Rao and Finch (76-7) though the results in this thesis will indicate that the role of nitrogen as a pyrite depressant may be hard to control.

The use of nitrogen in flotation is of particular relevance to this thesis so Section 2.4 is devoted to describing how nitrogen is produced for industrial applications.

2.3.2 Carbon dioxide

Carbon dioxide is produced as a by-product from nitrogen production at plants such as Gibraltar. In this case it is used as a substitute for sulphuric acid to reduce the pH in the molybdenum circuit (13).

Miller and co-workers have recently proposed the use of carbon dioxide to float fine coal. Carbon dioxide was used to produce a super-clean coal (so-called carbon dioxide coal flotation) by improving ash rejection and increasing the rate and extent of flotation for high-volatile bituminous coal (46). The success of the procedure is attributed to the coal's high adsorption potential for carbon dioxide.

Following this use in coal flotation another possible area is bitumen flotation. It is difficult, however, to imagine widespread application of carbon dioxide in froth flotation (98).

2.3.3 Steam

Many complex sulphide plants use steam as a conditioning gas prior to flotation. Two examples are Brunswick Mining and Mattabi Mines, as described in the previous section. Steam's normal role is to destroy residual reagents in solution after bulk flotation (68). However Berger and Evdokimov (10) have experimented with the use of steam in combination with air, as the flotation carrier gas. They tested this novel approach on several ores and observed reduced reagent consumption and flotation time, and improved extraction and selectivity. The effect of steam may be to improve froth cleaning by raising water temperature and aiding film drainage (67).

2.3.4 Sulphur dioxide

Sulphur dioxide is now probably the most commonly used gas beside air in flotation. Its use, however, is purely as a conditioner and it never acts as the carrier gas. In Canada, numerous plants use sulphur dioxide prior to complex sulphide flotation. Examples are given in Table 2.2.

Sulphur dioxide is mainly used for the depression of pyrite, sphalerite and galena (2,4,11,20,68,85). While Table 2.2 shows that many of the larger complex sulphide circuits in Canada use sulphur dioxide, other mines continue to use the older established depressants such as cyanide and zinc sulphate (e.g. Curragh Resources, Polaris Mine and Westmin Resources)(42,88). Yamamoto (106) gave two reasons for the replacement of cyanide with sulphur dioxide as a depressant - (1) cyanide is an environmental hazard and (2) cyanide tends to dissolve some of the precious metals in the ore. Gaudin (26), in fact, mentions that cyanide depression of sphalerite is only effective when significant quantities of iron are associated with the zinc. (This perhaps explains the use of cyanide at Curragh resources where the sphalerite contains roughly 15% iron in the matrix.)

Table 2.2: Some Canadian base metal operations using sulphur dioxide during flotation.

name:	minerals recovered	addition rate g/t
Brunswick Mining:	Cu/Pb/Zn/Ag	900
Geco:	Cu/Pb/Zn	430
Kidd Creek Mines,"A" div:	Cu/Zn	341
" " " ,"D" div:	Cu/Pb/Zn	381
Matagami Lake:	Cu/Pb/Zn	294
Mattabi Mines:	Cu/Pb/Zn/Ag	345

Significant research has recently been conducted into the chemistry of sulphur dioxide action in complex sulphide flotation. A major literature review of the theory behind the use of sulphur dioxide, or more precisely the derived ions such as the sulphite ion, in complex sulphide flotation is beyond the scope of this thesis. Some of the more important findings will, however, be covered.

At Brunswick Mining, Kidd Creek Mines and Mattabi Mines, sulphur dioxide is used to depress galena, sphalerite and pyrite at various stages in the process. All three plants add sulphur dioxide to the pre-aerator for pyrite and sphalerite depression prior to copper flotation. However, the two Noranda mines use sulphur dioxide to selectively float galena to the bulk concentrate and then to selectively depress galena in copper/lead and zinc/lead separation stages. This apparent contradiction of uses illustrates the complexity of sulphite ion / metal sulphide interactions. Peres (71) conducted an extensive study to evaluate the effectiveness of sulphur dioxide on the flotation of copper, lead and zinc. The depressing action of sulphur dioxide on different minerals is compared in Table 2.3.

TABLE 2.3 : Depressing action of sulphur dioxide in order of effectiveness.(71)

Sphalerite	most effectively depressed
Marmatite	
Pyrite	
Galena	
Covellite	
Chalcocite	
Chalcopyrite	least effectively depressed

Several mechanisms have been proposed for the depressing effect of sulphite ions on sphalerite flotation.

1. Sulphite ions may depress sphalerite through the formation of calcium or zinc sulphite films on the sphalerite surface (96,106). So, for effective sphalerite depression zinc or calcium ions must be available in solution. Table 2.4 shows that while some operations appear to coincide with this approach, others contradict it (2,4,64,68):

TABLE 2.4: A list of operations using sulphur dioxide for sphalerite depression, and the regulators used with it.

Operation	Amount SO_2 added	Other regulators
Mount Isa	500-1000	zinc sulphate sodium cyanide
Ainai, Japan	70-1000	zinc sulphate sodium cyanide
Hanava, Japan	70-1000	zinc sulphate
Brunswick Mining	150	none
Mattabi Mines	150-500	none
Kidd Creek Mines 'D' Division	350	none

2. Gaudin et al, taking an approach based on solid/solution equilibria (27), proposed that the depression of sphalerite was the result of lowering the cupric ion concentration in solution through reduction of the solution potential. Gaudin calculated that the addition of 600 g/tonne sulphur dioxide would effectively remove copper ions from solution (26).

3. Misra (64) found that the depression of sphalerite from chalcopyrite also stems from the decomposition of xanthate through action of sulphur dioxide. He found that the rate of decomposition is faster than that of xanthate adsorption onto the sphalerite surface, thus keeping the surface clear of collector. It is slower than the adsorption of xanthate onto chalcopyrite, however, and so cannot prevent a multi-layer coating of collector from forming on the chalcopyrite surface. The respective rates are dependent on sulphur dioxide and xanthate concentrations and the pH. Consequently all these factors influence the effectiveness of sulphur dioxide in promoting selective copper flotation from a copper/zinc mineral association (64).

Galena depression by sulphite ions seems to be the result of formation of lead sulphite on the galena surface. A pre-requisite to the formation of such a film is an oxidised galena surface, indicating that sulphur dioxide will only depress galena if it is heavily oxidised (91). Interestingly, Shimooisaka (91) found a similar mechanism for the depressing action of chromate ions on galena. This, however, was not restricted to oxidised galena, suggesting that chromate ions may be a more effective depressant. In fact Brunswick Mining originally adopted the use of chromate depression of sphalerite and pyrite, only to later reject the approach (66).

Sulphur dioxide also depresses pyrite. As sulphur dioxide is often a reducing agent (depending on the other ions in solution), pyrite depression is often considered electrochemical in nature. Dixanthogen is the most important hydrophobic species on the surface of pyrite (8,105). This can only form at pulp potentials higher than +0.22v vs S.H.E. By lowering the pulp potential below 0.22v vs S.H.E. the mechanism for pyrite collection using xanthates is blocked. However, Hill (38) found that sulphur dioxide does not reduce the potential in streams at Brunswick Mining, unless the pH is below 2. Further, sulphur dioxide is used to improve the selectivity of chalcopyrite flotation, and the rest potentials for xanthate adsorption on chalcopyrite and pyrite differ by only 80 mV. A more likely explanation is given by Yamamoto (106) and is similar to that proposed by Misra for sphalerite depression. While the adsorption of xanthate onto the pyrite surface is nct blocked by sulphite ions, they do desorb the xanthate effectively - the xanthate being decomposed to ethyl alcohol and carbon dioxide through the action of sulphite ions and oxygen. The applicable pH range is limited (pH 6-8) which would help to explain why sulphur dioxide can be used for selective pyrite depression (at pH 8) and flotation (at low pH - as formerly at Brunswick Mining).

Recently, Hoyack and Raghavan (43) showed that the depression of pyrite at higher pH levels (as at Kidd Creek Mines) may be due to electrochemical reactions leading to the formation of a hydrophilic surface product, $Fe_2(SO_4)_3.Fe(OH)_3$.

The potential value of sulphur dioxide in copper/nickel flotation has been assessed from time to time. Extensive pilot plant work on the use of sulphur dioxide in floating severely altered "pot-hole" copper/nickel/platinum group metal-bearing ores in South Africa resulted in improved pentlandite and pyrrhotite grades (45) but this has not been adopted commercially. Results from work by Peres (71), on pentlandite and chalcopyrite flotation are concordant with those noted in South Africa.

2.3.5 Other gases in flotation.

Hydrogen and oxygen are used as carrier gases in electroflotation. The basic principal of electroflotation is to produce hydrogen or oxygen through electrolysis, and to use the gas produced as the carrier gas in flotation. Electroflotation has two possible advantages:

1) The chemical nature of the gas can aid the flotation process. An example is the use of hydrogen to float cassiterite, where the gas reduces the oxide to metallic tin, aiding particle hydrophobicity. (41,104)

2) Finer bubbles can be produced, and the bubble size better controlled. This could aid the flotation of fine particles. The bubble sizes produced are typically 10-60µm in diameter, there being normally a compromise between bubble size and the stability of the froth produced.(9,31,50,104).

Electroflotation has not been adopted on an industrial scale yet, though testwork such as that on tin ores from Wheal Jane in Cornwall, England has suggested that it holds promise (41).

2.4 MEANS AND ECONOMICS OF PRODUCING NITROGEN (15).

2.4.1 Nitrogen supply options

There are six ways to supply nitrogen to a flotation plant:

* Combustion plant on-site.
* Membrane system on-site.
* Pressure Swing Adsorption system on-site.
* Cryogenic system on-site.
* Shipping-in liquid nitrogen.
* Closing flotation cells and recirculating the air, the oxygen will be consumed by the sulphide minerals.

The relative merits of each system will now be considered.

Combustion plant:

Combustion plants have been built on-site at a number of Canadian copper-molybdenum operations (e.g. Gibraltar Mines and Lornex Mining). They operate by using natural gas to combust the oxygen in the air by the following reaction:

$$2O_2 + CH_4 \rightarrow 2H_2O + CO_2$$

The quality of the nitrogen produced depends largely on the level of automatic control applied, being of the range of 95% - 99% N_2. Plant capacities are variable, though in the copper-molybdenum circuits they tend to be 20 - 30 tonnes per day.

Membrane system:

The membrane system effectively filters compressed air, taking advantage of the fast permeation rates of oxygen, carbon dioxide and water vapour to separate them from the more slowly permeating

Membranes employ the principle of selective permeation to separate gases. Oxygen permeates quickly through a semi-permeable membrane. Nitrogen permeates through at a much slower rate. The driving force which forces the oxygen through the membrane, is the difference between the two partial pressures of the feed and the oxygen discharge.

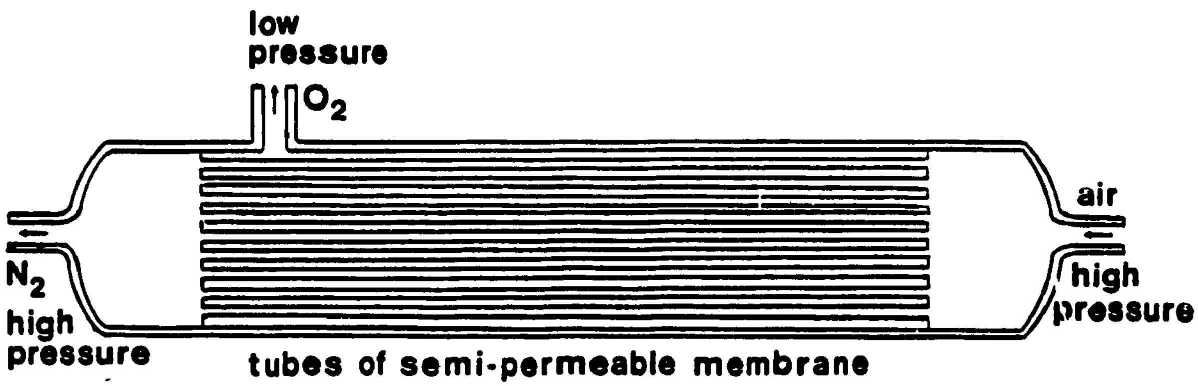


FIGURE 2.7 - Membrane system for producing nitrogen.

nitrogen. Compressed air enters a chamber filled with bundles of semi-permeable membranes formed into tiny, hollow fibres. The faster permeating gases, driven by a higher partial pressure inside the tubes than outside, permeate through the membrane and are collected at a relatively low pressure. Nitrogen remains inside the tubes and discharges the other end of the cylinder (see Figure 2.7). Such a plant produces nitrogen at roughly 95% purity, and has a relatively low capacity of 2.5 tonnes per day.

Pressure Swing Adsorption:

Pressure Swing Adsorption is a commonly used means of providing nitrogen of 99% purity. Compressed air is supplied at the bottom of the first bed where the proprietary sieve adsorbs the oxygen and other impurities (Figure 2.8). When this bed approaches saturation it switches to a regenerative phase while the second bed automatically begins the separation process. A nitrogen reservoir provides surge capacity and ensures a steady output. Plant capacities are generally up to 50 tonnes per day.

Cryogenic plants (101):

Cryogenic plants are the best means for providing large tonnages of nitrogen (more than 50 tonnes per day). They produce a very clean product (>99.9% N_2) by lowering the temperature of a supply of air to below the boiling point of oxygen (-183 deg C) and separating liquid oxygen from gaseous nitrogen. One stage produces a 50% oxygen containing liquid so two stages are needed to produce a high grade oxygen product. The Linde double column illustrated in Figure 2.9 is an example of a cryogenic system.

A Pressure Swing Adsorption (PSA) system is composed of two identical multi-layered beds which perform the separation process. Compressed air enters the bottom of the first bed where a proprietary sieve adsorbs oxygen and other impurities, allowing the nitrogen to pass through. When this bed approaches saturation it switches to a regenerative phase while the second bed automatically begins the separation process. The cycle is completed when the second bed reaches saturation and starts to regenerate and the first bed, once again, begins production.

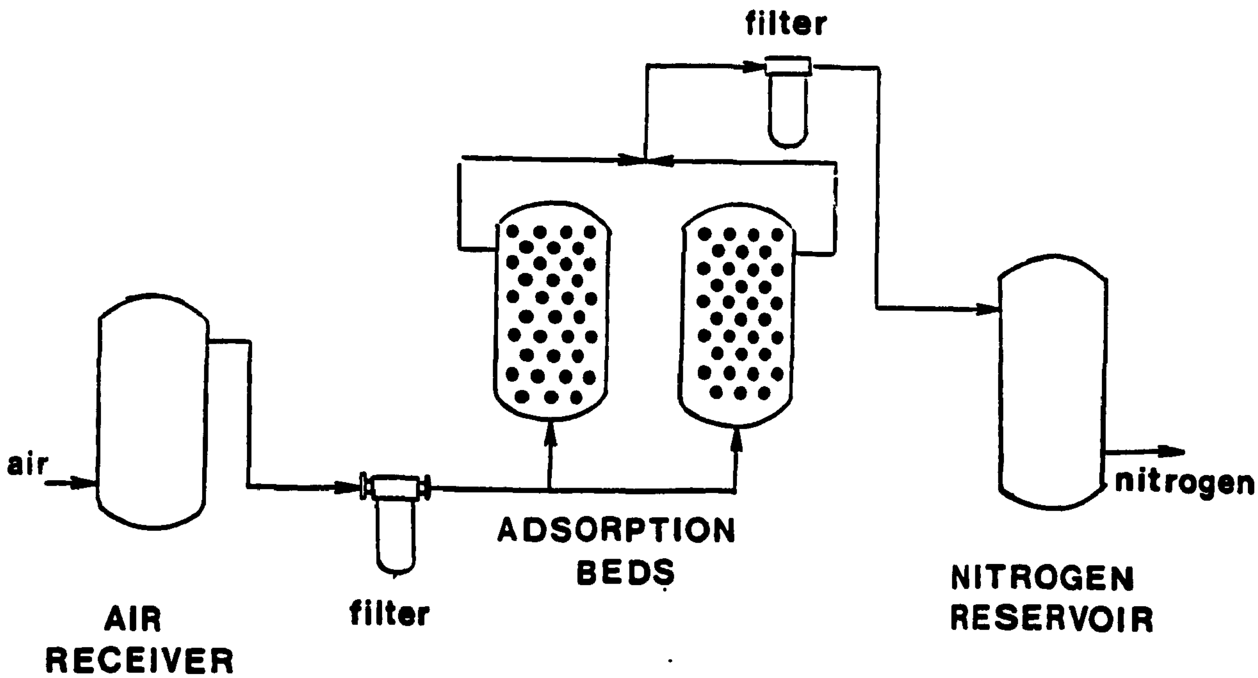


FIGURE 2.8 - Diagram of a Pressure Swing Adsorption system used for the production of nitrogen.

If nitrogen is required at any tonnage above 10-20 tonnes per day, shipping it in on trucks in liquid state is not likely to be viable. If nitrogen is only required occasionally, however, or if a low requirement is expected this may be a viable alternative. This is the only option if the consumer does not want any significant capital outlay.

Probably the most economical application of nitrogen in flotation in Canada is that of Island Copper at Port Hardy, B.C. Plant engineers closed the cells in the copper/molybdenum circuit and recirculated the gas (15). Some oxygen does leak into the system but this is consumed by reagent and the sulphides in the ore. The extra cost of consumed reagent is considerably less than the cost of producing nitrogen which itself would not be entirely clean of oxygen. Brenda Mines have also enclosed the flotation cells in the copper/molybdenum separation circuit (15).

2.4.2 Economic Comparison of the different options.

Table 2.5 compares the economics of the different sources of nitrogen. The capital cost of a nitrogen plant depends on the amount and quality of nitrogen to be produced. A typical plant producing 20 tonnes per day at 95% purity would cost roughly $750,000. A plant producing 400 tonnes per day of 99% nitrogen would cost roughly $8 million.

Air goes through tubes cooled in compartments which both cold oxygen and nitrogen flow. It is liquified in the bottom of the lower column where mainly nitrogen rises in gaseous form. It is also greatly cooled in the tubes surrounded by liquid oxygen from the upper column.

The oxygen-rich liquid is transferred to the middle of the upper column where condensation of mainly the oxygen occurs, the more volatile nitrogen rising to the compartment that cools the incoming air. The arrows show the route followed by the liquid and gases.

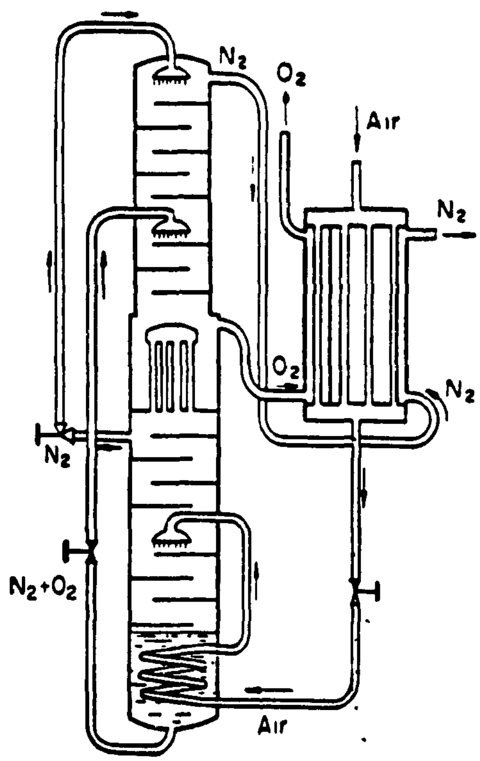


FIGURE 2.9 - Diagram of a double column for separating the oxygen and nitrogen in an air supply (from reference 15).

TABLE 2.5: Comparing the costs of the different means of producing nitrogen.

	cost per tonne N_2
Combustion plant	$10-$40
Membrane plant	n/a
Pressure Swing Adsorption	$50-$60
Cryogenic plant	$40
Supply of liquid nitrogen	$170

2.4.3 Other aspects of the use of nitrogen.

A plant that uses large tonnages of nitrogen will probably need to ensure the gas is disposed of for safety reasons. Thus some form of closed cells are going to be needed, which suggests that it would be worthwhile enclosing them completely.

Simply recirculating the air may not ensure consistent quality of nitrogen and will cause problems during start-up so some form of nitrogen producing capacity will probably be necessary. This would also permit a slight positive pressure to be maintained in the flotation cell, reducing the chance of air leaking into the system. While combustion plants have been the most popular they do have the disadvantage of not producing by-product oxygen. The oxygen, produced by membrane, P.S.A., and cryogenic plants can be used either elsewhere in the circuit (e.g. to improve a pre-aeration stage) or in plant boilers (e.g. for the concentrate driers). This would help off-set the cost of producing the nitrogen. The production of nitrogen will be considered further during the discussion stage of this thesis.

3. EXPERIMENTAL

3.1 ORE PREPARATION

Ore was obtained from the rod mill feed of three plants, Brunswick Mining, Mattabi Mines and Kidd Creek Mines ("D" division). The ore from Brunswick Mining was sampled in 1985 and 1987. The Mattabi plant was sampled in the spring of 1987 and ore from Kidd Creek Mines "D" division was sampled in the fall of 1987.

Plant rod mill feed material is generally too coarse to be ground in the McGill laboratory rod mill without being crushed finer. So each ore was dried (slowly in a cool oven, to avoid oxidation of the ore) and crushed using a laboratory gyratory crusher (Peacock Brothers) powered by a 5.6kW synchronous motor.

The crusher product was split into 1 kg samples using a 12-way rotary splitter, model M12 "prosplitter" (Desert Laboratories, Tucson AZ). The samples were stored dry at room temperature.

The ore was ground wet, at 64% solids by weight, in a stainless steel laboratory rod mill. The mill was 235mm long by 178mm diameter. A combined charge of mild and stainless steel rods was used, consisting of 11, 16mm by 230mm stainless steel rods, 2, 22mm by 194mm mild steel rods and 1, 35mm by 194mm mild steel rod. The total charge weight was 7750 g. Some tests were run using an entirely stainless steel charge but no change in flotation performance was observed.

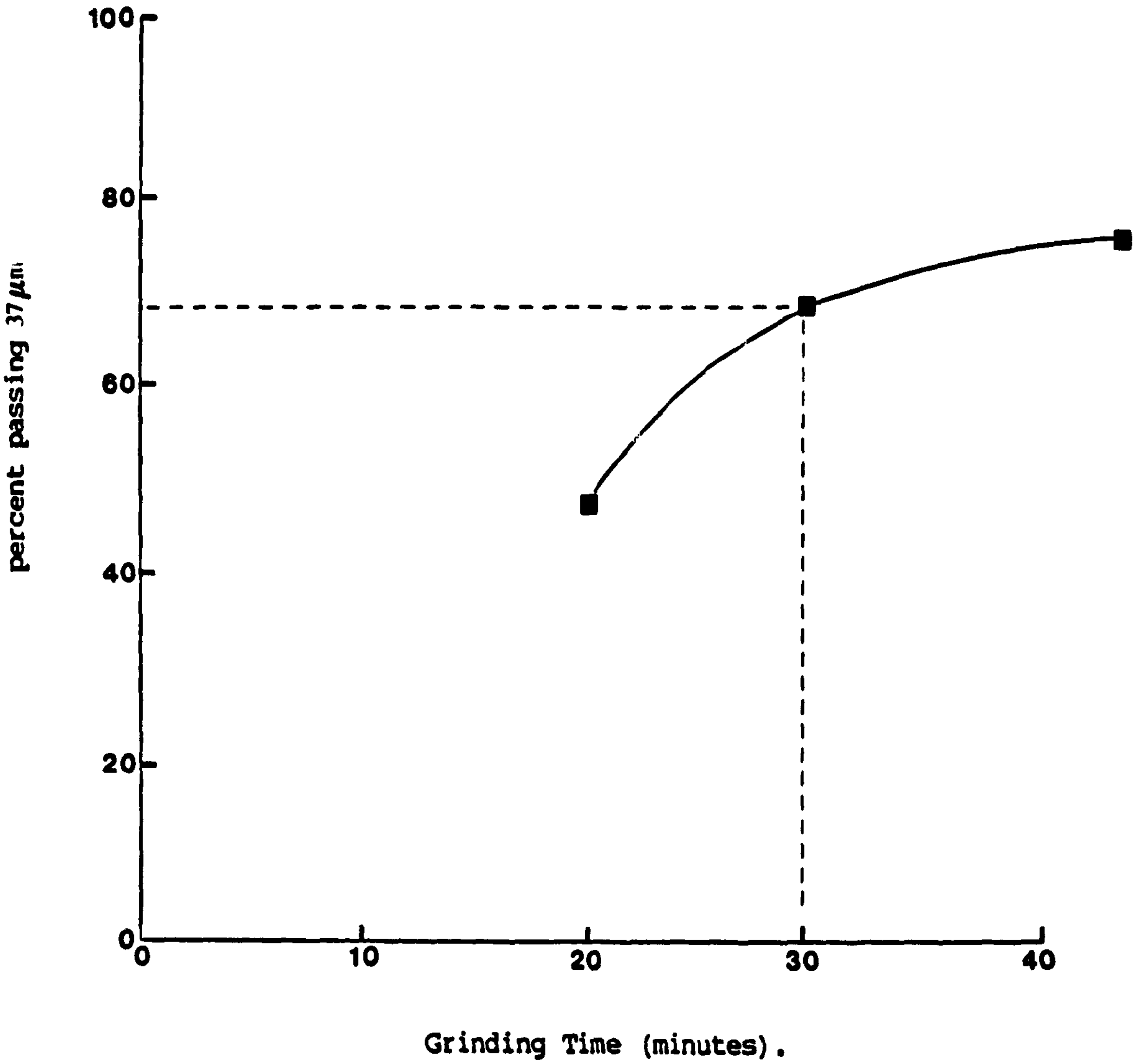


FIGURE 3.1 - Grinding calibration curve for tests on Brunswick Mining ore. The required grind was 65 % passing 37μm.

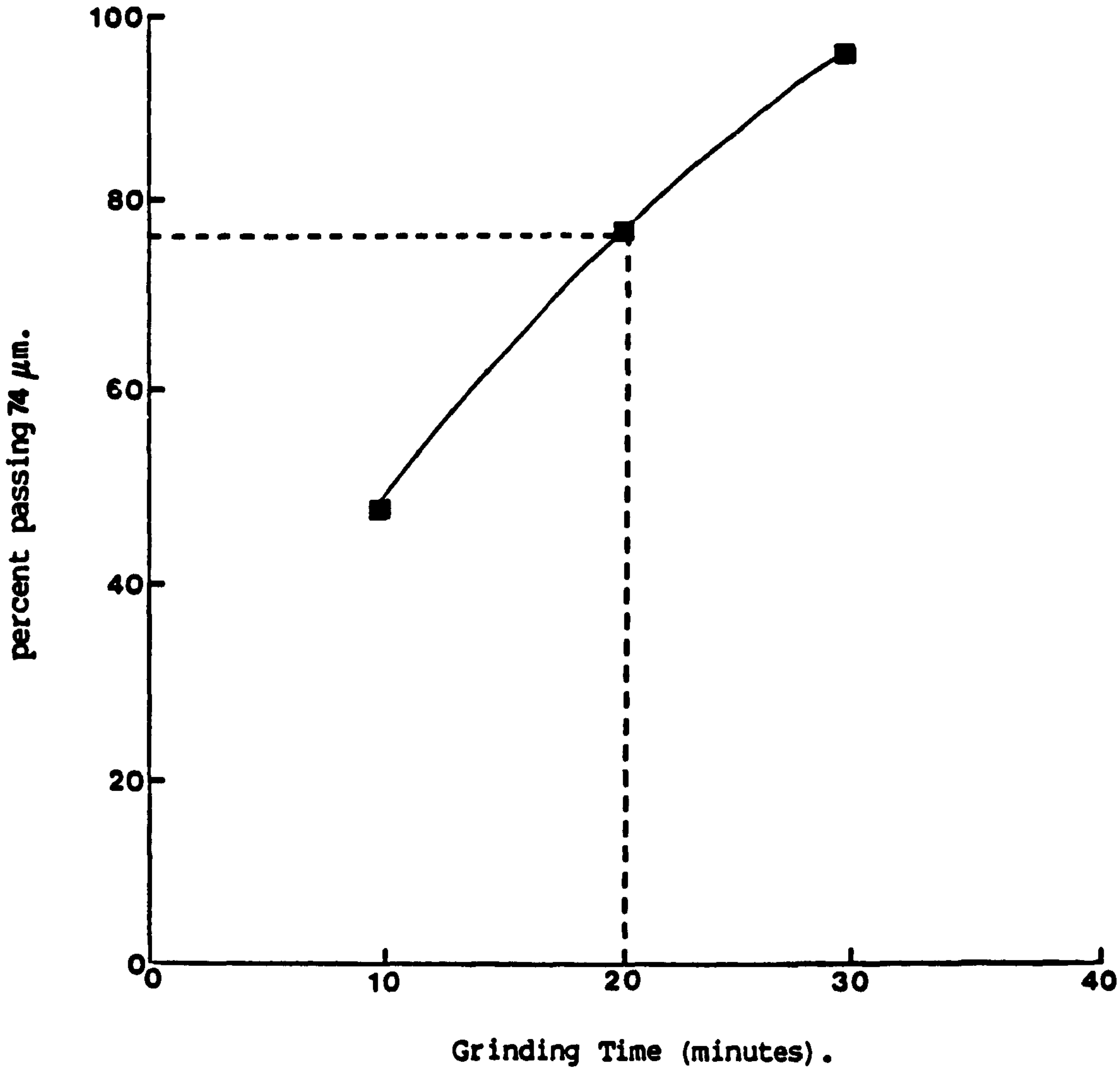


FIGURE 3.2 - Grinding calibration curve for tests on Mattabi ore. The required grind was 75 % passing 74 μm.

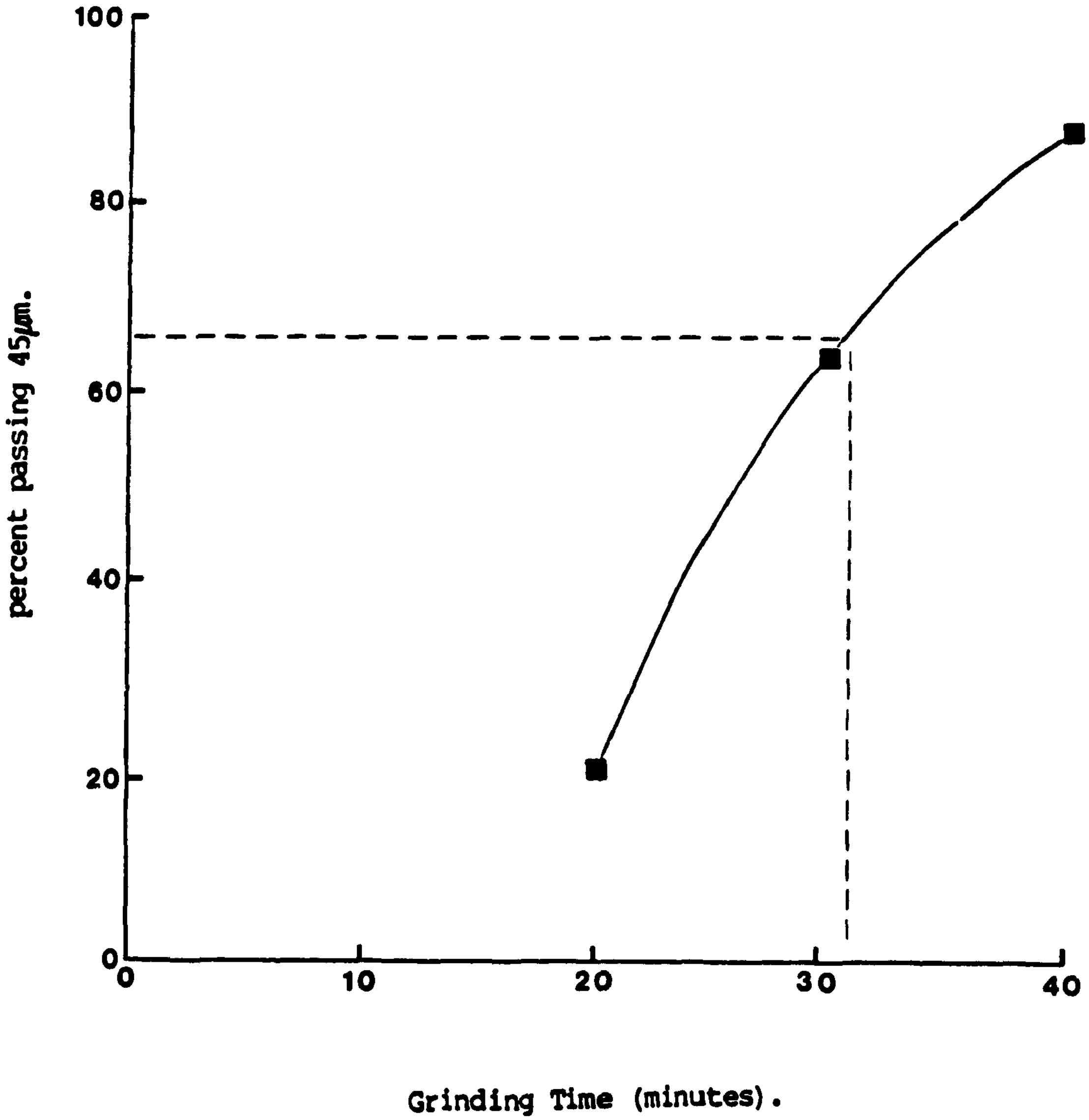


FIGURE 3.3 - Grinding calibration curve for tests on Kidd Creek ore. The required grind was 65 % passing 45μm.

Grinding time varied from ore to ore, and was determined using grinding tests and preparing a grind time vs size calibration curve. In each case the resultant particle size distribution was as similar as possible to that of the new flotation feed at the respective plant. The grinding test data is presented in Appendix 1, the calibration curves being Figures 3.1 to 3.3. The ground material was transferred from the mill to a 2.5 L Leeds-type flotation cell (Figure 3.4).

3.2 FLOTATION

While flotation test reproducibility is always limited by errors in sampling and variations in the operation of a test (6,19), the Leeds cell considerably reduces the amount of error. The cell, designed by C.C.Dell in 1981 has been analysed extensively by researchers in the United Kingdom and South Africa (7,19,67). They concluded that:

* The open top nature of the cell allows excellent access for filling and froth removal, thus maintaining a consistent froth depth.
* Good control of the impellor speed (through digital readout) and pulp level (controlled automatically or manually) enhances reproducibility.
* Excellent air dispersion characteristics through use of baffles leading to good flotation performance and stable, deep froths.

The author used a Leeds cell in South Africa, for roughly 150 tests on a magnetic concentrate from Merensky ore (62). Based on that experience, and the experience from the testwork reported in this thesis the author can confirm these observations.

The standard flotation procedures for the three ores are described in Tables 3.1 to 3.4. Most tests, however, were run under specific conditions. These conditions are listed with the respective results sheet in the appendix.

Conditions in the laboratory tests were designed to be similar to standard plant conditions, with one notable exception. Tests at McGill University used zinc sulphate as the principal sphalerite depressant during copper,lead bulk flotation. The main reason for this is the difficulty associated with handling and storing sulphur dioxide at the University, owing to its hazardous nature. Tests at Brunswick Mining compared the use of zinc sulphate with sulphur dioxide, and found that the metallurgical results achieved using the two approaches are very similar. In some tests on Mattabi ore sodium sulphite was used as a substitute for sulphur dioxide. Results from this testwork are descibed in Section 4.2.

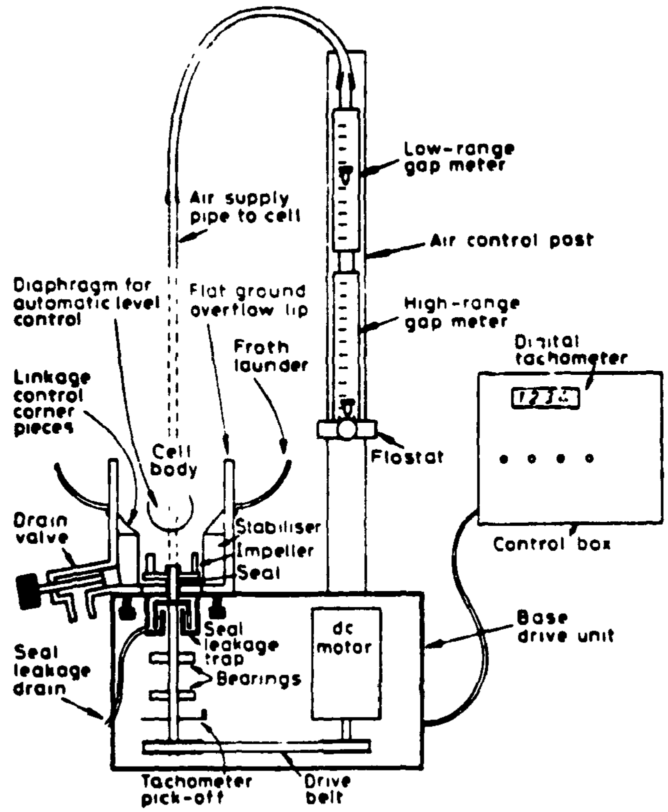


FIGURE 3.4 - Diagrammatic representation of the Leeds flotation cell used in the tests at McGill University.

TABLE 3.1: The standard flotation procedure for tests on Brunswick Mining ore at McGill University:

GRIND:	
sample size	1 kilogram
mill	steel rod mill (see text)
charge	mild/stainless steel rods (see text)
reagents	zinc sulphate, 1200 g/t*
pH	natural
pulp density	2.1 Kg/litre (64% solids)

note: mill pre-cleaned by grinding with silica for 5-10 minutes.

FLOTATION CELL:	Leeds open-top, 2.5 litre
impellor speed	1100 rpm
froth depth	1-2 centimetres
pulp density	1.3 kg/litre (31% solids)
PRE-AERATION:	
Time	10 minutes
Gas flowrate	3-5 litres/minute
pH	8.5, modified by lime
BULK FLOTATION:	
Total flotation time	4 minutes
collectors	Sodium isopropyl xanthate (total 80 g/t)*
frother	MIBC
Gas flowrate	3-5 litres/minute
ZINC FLOTATION:	
Copper Activation	
- activator	Copper sulphate, 1200 g/t*
- conditioning	5 minutes.
- pH	10.0, adjusted using lime
flotation	
- collector	sodium isopropyl xanthate (total 80 g/t)*
- time	7 to 11 minutes
- frother	MIBC

* prepared each day.

note: Collector prepared as 1% solution.
Copper sulphate prepared as 10% solution.
Zinc sulphate prepared as 10% solution.

TABLE 3.2: The standard flotation procedure for tests on Mattabi Mines ore at McGill University:

GRIND:	
sample size	1 kilogram
mill	steel rod mill (see text)
charge	mild/stainless steel rods (see text)
reagents	zinc sulphate, 1100 g/t* or sodium sulphite.
pH	9.5, modified by soda ash
pulp density	2.1 Kg/litre (64% solids)

note: mill pre-cleaned by grinding with silica for 5-10 minutes.

FLOTATION CELL:	Leeds open-top, 2.5 litre
impellor speed	1100 rpm
froth depth	1-2 centimetres
pulp density	1.3 kg/litre (31% solids)
PRE-AERATION:	
Time	10 minutes
Gas flowrate	3-5 litres/minute
pH	9.5, modified by soda ash
BULK FLOTATION:	
Total flotation time	4 minutes
collectors	Sodium ethyl xanthate, 2.5 g/t and dithiophosphate, 2.5 g/t*
frother	Dowfroth 250
Gas flowrate	3-5 litres/minute
pH	9.5, modified by soda ash
ZINC FLOTATION:	
Copper Activation	
- activator	Copper sulphate, 1200 g/t*
- conditioning	5 minutes.
- pH	10.0, adjusted using lime
flotation	
- collector	sodium ethyl xanthate (total 80 g/t)*
- time	7 minutes
- frother	MIBC

* prepared each day.

note: Collector prepared as 1% solution.
Copper sulphate prepared as 10% solution.
Zinc sulphate or sodium sulphite prepared as 10% solution.

TABLE 3.3: The standard flotation procedure for tests on Kidd Creek Mines ore, "D" division at McGill University (5):

GRIND:	
sample size	1 kilogram
mill	steel rod mill (see text)
charge	mild/stainless steel rods (see text)
reagents	zinc sulphate, 1000 g/t*
pH	9.0, modified by lime
pulp density	2.1 Kg/litre (64% solids)

note: mill pre-cleaned by grinding with silica for 5-10 minutes.

FLOTATION CELL:	Leeds open-top, 2.5 litre
impellor speed	1100 rpm
froth depth	1-2 centimetres
pulp density	1.3 kg/litre (31% solids)
PRE-AERATION:	
Time	10 minutes
Gas flowrate	3-5 litres/minute
pH	10.5, modified by lime
BULK FLOTATION:	
Total flotation time	4 minutes
collectors	Sodium isopropyl xanthate (total 20 g/t)*
frother	MIBC
Gas flowrate	3-5 litres/minute
pH	10.5, modified by lime
ZINC FLOTATION:	
Copper Activation	
- activator	Copper sulphate, 1000 g/t*
- conditioning	5 minutes.
- pH	11.0, adjusted using lime
flotation	
- collector	sodium isopropyl xanthate (total 80 g/t)*
- time	7 minutes
- frother	MIBC

* prepared each day.

note: Collector prepared as 1% solution.
Copper sulphate prepared as 10% solution.
Zinc sulphate prepared as 10% solution.

TABLE 3.4: The standard flotation procedure for tests on Brunswick Mining ore at the plant laboratory (3).

GRIND:	
sample size	2 kilogram
mill	steel rod mill (Denver mill)
charge	stainless steel rods
reagents	sulphur dioxide, 150 g/t*
pH	8.0, modified by soda ash
pulp density	2.2 Kg/litre (66% solids)
FLOTATION CELL:	Wemco, 3 litre
impellor speed	1500 rpm
froth depth	1-2 centimetres
pulp density	1.9 kg/litre (55% solids)
PRE-AERATION:	
Time	20 minutes
Gas flowrate	valve fully open
pH	9.2, modified by soda ash
BULK FLOTATION:	
Total flotation time	7 minutes
collectors	Plant xanthate (total 50 g/t)*
frother	MIBC
Gas flowrate	valve fully open
pH	9.2, modified by soda ash
ZINC FLOTATION:	
Copper Activation	
- activator	Copper sulphate, 700 g/t*
- conditioning	10 minutes.
- pH	10.1, adjusted using lime
flotation	
- collector	plant xanthate (total 50 g/t)*
- time	7 minutes
- frother	MIBC

* prepared each day.

note: Collector prepared as 1% solution.
Frother prepared as 1% solution.
Copper sulphate prepared as 10% solution.
Zinc sulphate prepared as 10% solution.

A Fisher Scientific "Accumet" pH meter (Model 815 P) with associated electrode, was used for pH measurement. Dissolved oxygen measurements were made using an Orion Research dissolved oxygen probe, model 97-08-00, linked to the above meter.

Pulp potentials were monitored using a system described by Labonte (52). A gold coil electrode was used as a sensing electrode and was measured against a standard calomel electrode. Other factors (such as pH and temperature) affect measurements of pulp potential and were accounted for using the system illustrated by Figure 3.5. Measurements were processed on-line using the program "FLDATAC" on an IBM computer, giving read-outs at 6 second intervals.

3.3 SAMPLE PREPARATION, ASSAY AND METALLURGICAL BALANCING

Samples from the flotation tests were dried in electric ovens at below 100 deg C, again to avoid oxidation. The dried samples were weighed and, if necessary, split before being sent for assay. Most samples were assayed by Le Centre de Recherches Minerales in Sainte Foy (Quebec), or at the respective mine assay laboratories. A mass balance was generated from the results using the IBM-Lotus 1-2-3 spreadsheet program.

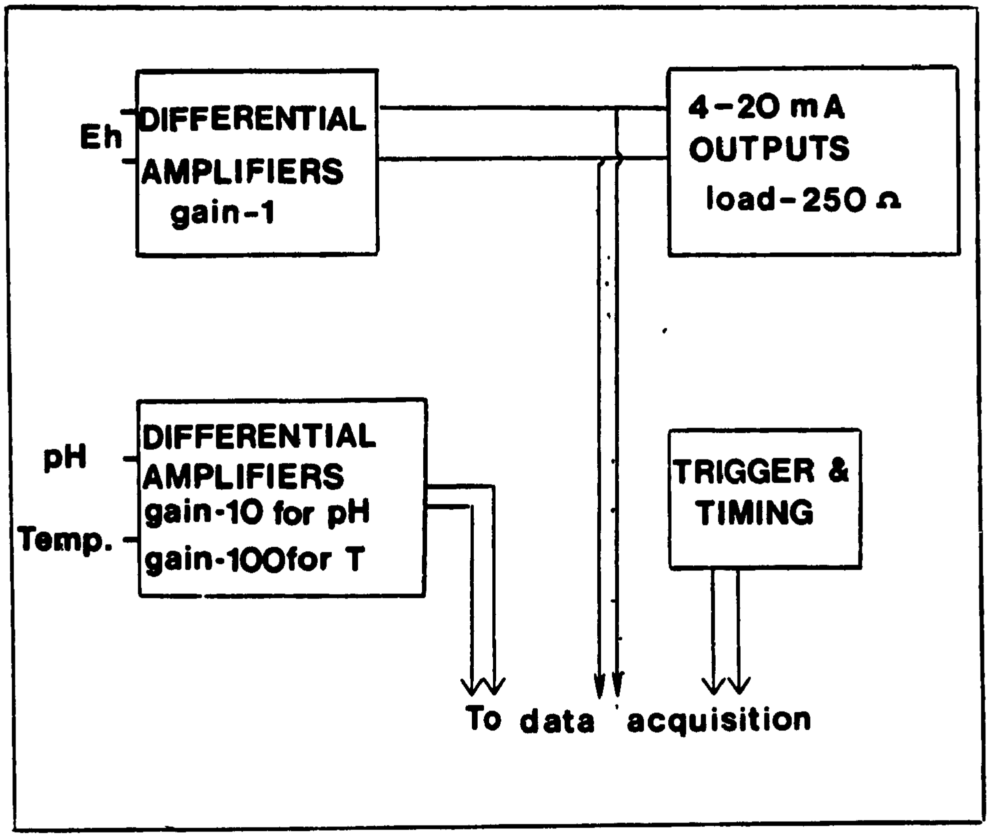


FIGURE 3.5 - Block diagram of the readings used and how they are weighted (amplified) in Labonté's potential measuring system. (from 52)

4. RESULTS

4.1 FLOTATION TESTWORK ON BRUNSWICK MINING ORE

Perhaps the principal problem facing metallurgists at Brunswick Mining is the flotation separation of sphalerite and pyrite. The current flowsheet only allows a 30% zinc rougher concentrate grade to be produced, because of significant mis-direction of pyrite. As a result operators have to rely greatly on the cleaner circuit to make grade, resulting in a relatively complex cleaner circuit and a relatively low grade of zinc (51%) in the final concentrate.

Recently, McGill University has been involved in research to find ways of improving metallurgy in the zinc circuit at Brunswick Mining. Hill (39) concentrated on the mineralogy of the circuit; this thesis considers the chemistry behind pyrite flotation.

This thesis applies some novel concepts, largely derived from the increased understanding of flotation chemistry, to improve selectivity in zinc flotation. As discussed in Section 2.1, of particular interest is the possibility of collectorless flotation of pyrite and the use of nitrogen to improve zinc/pyrite selectivity.

The results described in this section show that collectorless flotation of Brunswick Mining ore is largely ineffective. The tests did, however, identify that pyrite flotation can be strongly promoted in the presence of a nitrogenated, or more correctly, a de-oxygenated environment. A procedure was developed by which a high-grade pyrite concentrate could be produced prior to zinc flotation.

4.1.1 Standard test and statistical comparison with plant results

In such a program of laboratory tests, it is important to develop a standard procedure which produces similar metallurgical results to the respective production plant. As a consequence, the first part of this section is devoted to determining standard conditions. As the chief area of interest is zinc,pyrite separation all tests generally start with a standard copper,lead bulk flotation stage. (This repeated bulk flotation stage acts as a continual check on test reproducibility.)

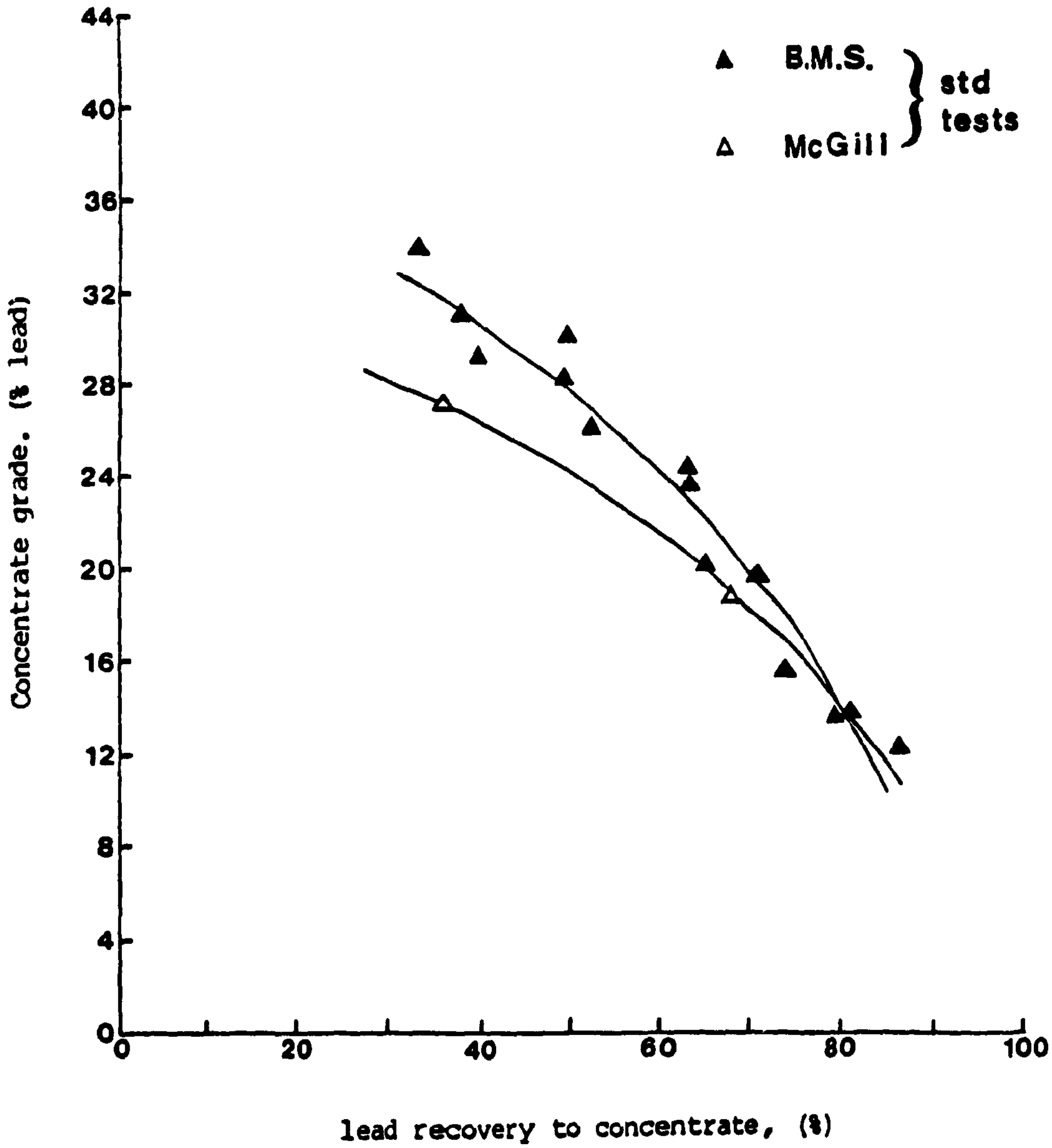


FIGURE 4.1 - Grade vs recovery of lead to the bulk concentrate, from tests at Brunswick Mining employing the Brunswick Mining and McGill University standard procedures.

4.1.1.(a) Results from standard tests employing the McGill procedure.

The tests on Brunswick Mining ore in the McGill University laboratory led to slightly lower combined copper, lead grades in the bulk rougher concentrate than those reported at the plant, at equal recoveries (see Table 4.1).

When the standard Brunswick Mining laboratory test procedure was compared to the McGill procedure, using the same mill and flotation cell the respective results are similar (particularly at typical plant recoveries of 70%, see Table 4.2 and Figure 4.1). This suggests that the improved copper / lead flotation selectivity is a result of a specific plant condition rather than the technique applied. A notable feature from this testwork is the equivalent effect of using sulphur dioxide and zinc sulphate on the flotation depression of pyrite and sphalerite.

At McGill University, the ensuing zinc flotation stage led to a 25% zinc rougher concentrate grade at 72% recovery (or 91.6% recovery from the zinc flotation feed). Again, pyrite rejection in the plant was better than in the laboratory testwork, leading to a 34% concentrate grade at 71% recovery. This may be explained by the addition of the zinc scavenger concentrate to the feed of the plant zinc circuit, raising the zinc assay of the rougher feed.

The laboratory testwork performed on-site at Brunswick Mining included, in each case, some form of pyrite flotation stage prior

TABLE 4.1: Copper, lead, zinc, and iron grades and recoveries in the bulk flotation concentrates from laboratory tests at McGill University and Brunswick Mining #12 plant

	test number 10-301		plant data	
	bulk copper/lead rougher			
	grade (%)	recovery (%)	grade (%)	recovery (%)
copper	1.14 /	76.1	1.50 /	76.4
lead	10.60 /	75.3	16.70 /	76.7
zinc	7.54 /	21.7	10.50 /	19.3
iron	33.85 /	27.8	28.27 /	17.8

TABLE 4.2: Copper, lead, zinc, and iron grades and recoveries in the bulk flotation concentrates, from laboratory tests using McGill University and Brunswick Mining laboratory procedures. Conditions were otherwise identical. Tests performed at Brunswick Mining.

	McGill procedure		BMS procedure	
	bulk copper/lead rougher			
	grade (%)	recovery (%)	grade (%)	recovery (%)
copper	1.63 /	57.8	1.58 /	69.4
lead	18.72 /	67.6	19.89 /	72.3
zinc	8.81 /	14.4	9.00 /	14.4
iron	22.99 /	13.4	27.53 /	14.8

TABLE 4.3: Comparison of metal recoveries from bulk copper, lead rougher flotation during laboratory tests and on the plant.

	recoveries (%)			
	standard tests	other lab. tests		plant data
	mean	mean	s.d.	mean
copper	76.1	74.8	3.7	76.4
lead	75.3	73.0	8.5	76.7
zinc	21.7	18.8	5.2	19.3
iron	27.8	17.7	3.2	20.2

to zinc roughing. The zinc flotation feed, therefore, was different in constitution in these cases and the zinc flotation stages cannot be compared.

In most tests a standard bulk copper,lead flotation stage was adopted prior to pyrite and/or zinc flotation. Table 4.3 lists metal recoveries from bulk flotation in the standard test, on the plant, and the mean and standard deviation of all the other tests in the project.

The table shows that deviations from the mean were relatively small. As laboratory flotation tests are always subject to such variable conditions as ore quality, water quality and grind, results have an inherent inconsistency, these relatively low standard deviations are judged acceptable. Table 4.3 also shows that laboratory test results deviate only slightly from the metallurgy achieved on the plant. At the 95% confidence level, the deviations from the plant results are insignificant.

4.1.2 Collectorless flotation of Brunswick Mining ore.

In this set of tests the potential for collectorless flotation of Brunswick Mining ore was assessed. Tests in the section followed the sequence:

collectorless flotation
▽
bulk flotation (tests 10-101,10-102)
▽
zinc flotation

Both air and nitrogen were used as the carrier gases.

Generally, no appreciable collectorless flotation of Brunswick Mining ore in air was observed. However, in one test a longer pre-aeration period resulted a 100% improvement in the collectorless recovery of chalcopyrite. The overall recovery of chalcopyrite, however, was still less than 40% (see Table 4.4).

When a bulk concentrate was floated with collector after the collectorless float, the resulting copper and lead grades were low, reflecting significant flotation of zinc and iron sulphides to the bulk concentrate (see Table 4.5). This in turn led to zinc recovery of only 60% to the zinc concentrate, at a grade of 30% zinc. Zinc flotation without prior bulk flotation led to a low grade zinc concentrate due to the flotation of lead and copper sulphides which had been depressed during the previous collectorless stage. There appears, therefore, to be no advantage in incorporating collectorless flotation using air into the Brunswick Mining flowsheet.

One test was run to check the collectorless flotation of Brunswick material in nitrogen. The results were similar to those in air, showing generally poor flotation of all minerals (see Table 4.6).

Following flotation of the collectorless concentrate, bulk flotation in nitrogen using xanthate was attempted. These results are also outlined in Table 4.6, and indicate strong flotation of pyrite and fairly strong flotation of galena. Other minerals floated poorly.

The remainder of the pyrite floated in the zinc flotation stage. As a result, only a low grade zinc concentrate could be produced.

TABLE 4.6: Metal grades and recoveries from collectorless flotation in nitrogen of ore from Brunswick Mining, after grinding and nitrogen conditioning.

	Collectorless flotation concentrate.	
	grade (%)	recovery (%)
copper	0.37	11.9
lead	4.81	15.8
zinc	8.68	10.8
iron	26.30	11.5
	copper,lead bulk flotation concentrate	
	grade (%)	recovery (%)
copper	0.48	30.7
lead	4.91	53.5
zinc	2.57	10.3
iron	39.09	56.8
	zinc flotation concentrate	
	grade (%)	recovery (%)
copper	0.40	31.7
lead	3.28	26.2
zinc	24.48	74.8
iron	22.51	24.0

TABLE 4.4: Metal grades and recoveries from collectorless flotation in air of ore from Brunswick Mining, after grinding and different levels of pre-aeration.

tests	10-103,10-104		10-102	
pre-aeration time (min)	10		25	
	grade/recovery		grade/recovery	
	(%)	(%)	(%)	(%)
copper	0.62/	16.7	1.07/	36.8
lead	5.91/	16.5	5.60/	20.0
zinc	7.62/	9.4	7.10/	9.5
iron	33.51/	10.5	28.10/	11.8

TABLE 4.5: The metal grade/recovery relationships from flotation of the copper, lead bulk concentrate in test 10-102.

	copper, lead bulk flotation concentrate	
	grade (%)	recovery (%)
copper	0.70	43.6
lead	9.57	61.1
zinc	9.92	24.0
iron	30.24	24.7

4.1.3 Assessing the effects of aeration and nitrogen on bulk flotation.

The standard pre-treatment method used before bulk flotation involves up to 30 minutes aeration. This is believed to depress pyrite and improve copper and lead grades in the bulk concentrate. (48)

The results described in this section confirm the role of pre-aeration in pyrite depression and extend this to show that nitrogen can promote pyrite flotation.

The first tests omitted the aeration stage used at Brunswick Mining (and commonly elsewhere). Short periods of xanthate conditioning were used in a nitrogen environment before each bulk flotation step. This resulted in strong flotation of copper, lead and iron-bearing minerals, as indicated by the respective high recoveries in Table 4.7. The amount of zinc mis-directed to the bulk concentrate, possibly by entrainment, limited the grade/recovery characteristics of the subsequent zinc float. Table 4.7 shows that an improvement in zinc grade can be made by removing the pyrite prior to zinc flotation.

The results from these tests show the value of pre-aeration in attaining good pyrite depression. Flushing the oxygen out before xanthate conditioning apparently has no effect on the xanthate collection mechanism. As flotation was in air, it can be argued that the flotation gas provided the necessary oxygen for successful collector-mineral interaction. This is checked in the next section.

TABLE 4.7: Sequential Flotation of bulk copper, lead and zinc concentrates in air following grinding, nitrogen conditioning and xanthate collection.

tests 10-209,10-210	Bulk copper, lead rougher concentrate grade (%)	recovery (%)
copper	0.55	82.5
lead	5.15	79.4
zinc	5.01	34.4
iron	38.72	68.3

	zinc rougher concentrate grade (%)	recovery (%)
copper	0.19	9.8
lead	1.99	8.7
zinc	32.96	62.0
iron	18.11	9.1

So far, the removal of oxygen during conditioning of the bulk flotation feed has strongly promoted the flotation of pyrite. To further assess the effect of deoxygenated environments on pyrite flotation, the next tests avoided the use of air at any stage after grinding. The results are summarised by Table 4.8.

The overall recoveries of all four elements in two of the three tests were over 80%. As nitrogen was used throughout the tests this suggests that the use of nitrogen does not impede collector-mineral interaction. Whether pyrite is being promoted by nitrogen is unclear from this testwork. It could be argued that air flotation without pre-aeration would produce the same result. This is checked in the next section.

TABLE 4.8: Flotation of (1) a bulk copper, lead concentrate and (2) a zinc concentrate with xanthate, in nitrogen following grinding and nitrogen conditioning.

(1) bulk copper, lead flotation

ref	10-208 grade (%)	10-208 recovery (%)	10-205 grade (%)	10-205 recovery (%)	10-206 grade (%)	10-206 recovery (%)
copper	1.15/	64.4	0.53/	84.7	0.48/	84.8
lead	3.58/	18.0	4.89/	81.4	5.15/	85.2
zinc	4.74/	12.4	4.22/	28.8	5.06/	38.1
iron	37.41/	23.7	38.84/	75.7	38.66/	80.0

(2) zinc concentrate

ref	10-208 grade (%)	10-208 recovery (%)	10-205 grade (%)	10-205 recovery (%)	10-206 grade (%)	10-206 recovery (%)
copper	0.33/	11.5	0.20/	8.8	0.19/	6.4
lead	8.02/	25.4	1.76/	8.1	1.41/	4.7
zinc	27.44/	45.0	35.24/	66.6	39.71/	55.5
iron	18.37/	31.0	17.21/	9.3	13.44/	5.2

Each individual result is included in Table 4.8 to show that the action of nitrogen in promoting pyrite flotation directly after grinding and nitrogen conditioning, can be unreliable (compare Tests 10-208 and 10-206). While the occasional depression of pyrite can be explained using our current understanding of flotation electrochemistry, through a lower pulp potential, this would not explain the depression of galena.

Zinc flotation is highly sensitive to the metallurgy achieved in the previous stage (bulk flotation). Where substantial flotation of copper, lead and iron sulphides has been achieved as in 10-205 and 10-206 zinc grades and recoveries are higher.

The object of the next set of tests was to assess whether the promotion of pyrite could be attributed to the use of nitrogen or the omission of a pre-aeration stage. Strong flotation of copper- and lead-bearing minerals was consistently observed. Pyrite also floated strongly, and this is reflected in the poor copper, lead grades.

Eliminating pre-aeration had little effect on zinc recovery to the copper, lead bulk concentrate. Zinc recovery increased from 18% to 21% indicating, perhaps, more entrainment in the bulkier concentrates. The ensuing zinc flotation produced low grade zinc concentrates as illustrated by Table 4.9.

Once again the value of pre-aeration in depression of pyrite has been shown. The results here suggest that pyrite will be activated by any de-oxygenating system (such as conditioners and thickeners), but nitrogen conditioning and nitrogen flotation still lead to the strongest pyrite flotation, as illustrated by Figure 4.2.

FIGURE 4.2: Summary of the effect of different gases and pre-treatment steps on the recovery of pyrite in bulk flotation.

pre-treatment (conditioning)	flotation gas		pyrite recovery (%) 0 20 40 60 80
nitrogen 3 min	nitrogen	80%	||||||||||||||||||||||||
nitrogen 3 min	air	68%	||||||||||||||||||||
none	air	45%	||||||||||||||
air 10 minutes	air	20%	|||||||

TABLE 4.9: Flotation of (1) a bulk copper, lead concentrate and (2) a zinc concentrate in air with xanthate, after grinding, no pre-conditioning.

(1)	Cu,Pb concentrate mean grade (%)	Cu,Pb concentrate mean recovery (%)
copper	0.8	81.4
lead	9.8	82.6
zinc	5.9	22.4
iron	32.4	45.4

(2)	zinc flotation mean grade (%)	zinc flotation mean recovery (%)
copper	0.2	13.8
lead	1.6	10.4
zinc	21.3	62.2
iron	23.6	26.3

Repeated tests have shown that the use of nitrogen can promote the flotation of pyrite. They have also shown that nitrogen has little effect on the flotation of unactivated sphalerite . So the use of nitrogen can promote pyrite flotation selectively from sphalerite. Such removal of pyrite can improve the ensuing zinc flotation concentrates grade. For this effect to be useful, pyrite must also be extracted separately from the copper and lead-bearing minerals. To this end, a bulk float is now produced in the conventional way, followed by pyrite flotation.

4.1.4 Flotation of a selective pyrite concentrate after standard copper, lead bulk flotation.

In this section, the use of nitrogen for the selective removal of pyrite after standard copper,lead bulk flotation is considered. Results show that air flotation of the pyrite recovers only 23% of the iron from the bulk flotation tails. The use of nitrogen, however, leads to considerably higher recoveries of pyrite.

Standard copper, lead bulk flotation stage results from these tests follow those established in Section 4.1.1 (see Table 4.10). Table 4.10 also shows that further flotation in air yields a pyrite concentrate with both low grade and recovery of pyrite.

TABLE 4.10: Standard flotation of a copper, lead bulk concentrate, followed by the flotation of a pyrite rougher concentrate in air.(Test 10-202)

metal	bulk flotation grade (%)	bulk flotation recovery (%)	pyrite flotation grade (%)	pyrite flotation recovery (%)
copper	1.45	68.4	0.24	9.3
lead	15.16	74.0	3.05	12.0
zinc	9.13	16.4	8.4	12.2
iron	29.15	18.5	36.0	18.4

Pyrite scavenger flotation was next attempted using nitrogen and air in different tests. The results are compared in Table 4.11 and Figure 4.3, which shows that while flotation in air had reached its recovery limit, the use of nitrogen activated the pyrite, flotation yielding much improved grades and recoveries of iron.

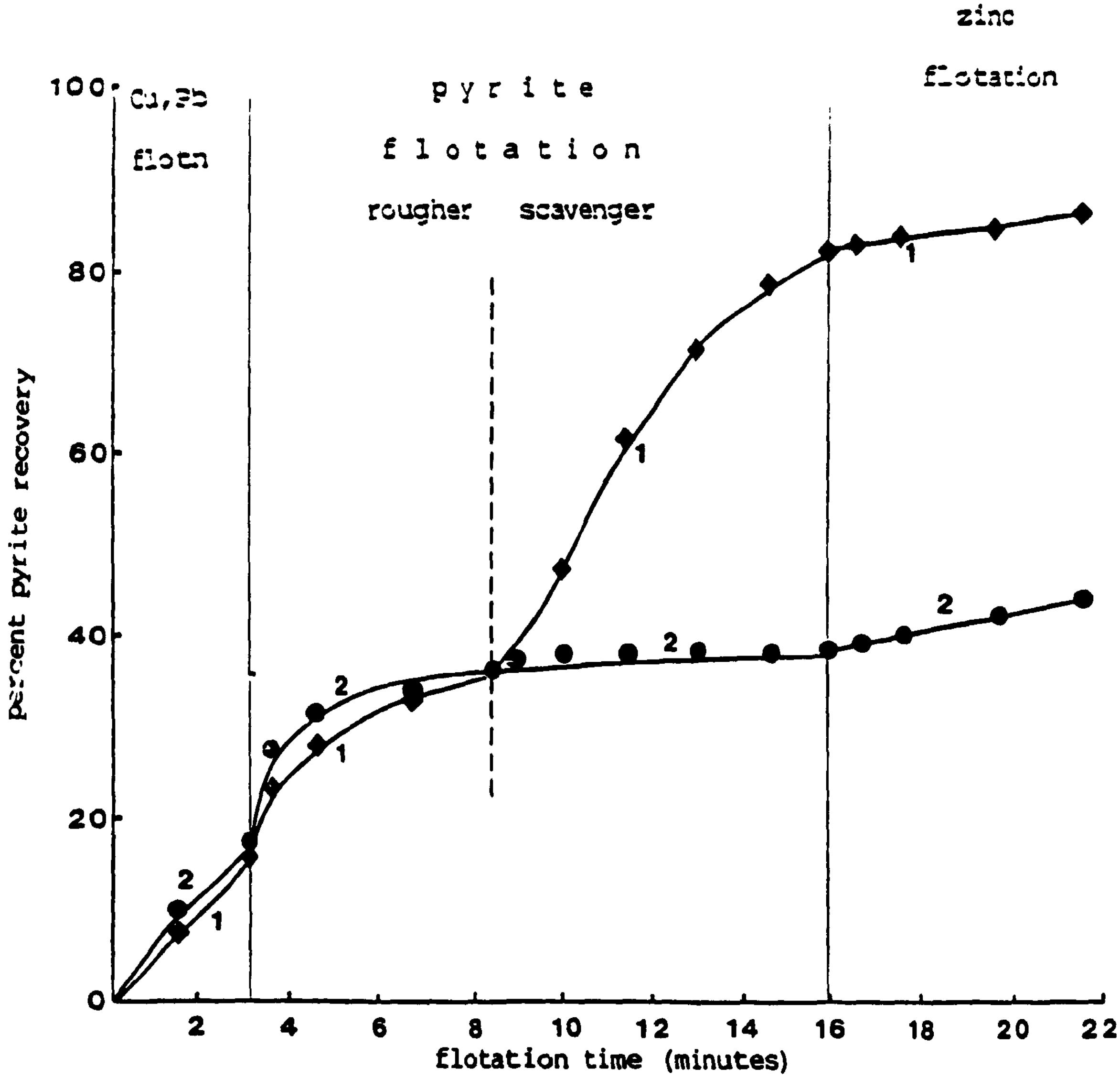


FIGURE 4.3 - Recovery of pyrite as a function of flotation time, showing the effect of nitrogen on pyrite flotation.

Carrier gas used:

	1	2
bulk flotation	air	air
pyrite rougher	air	air
pyrite scavenger	nitrogen	air
zinc flotation	air	air

TABLE 4.11: The flotation of a pyrite scavenger concentrate following bulk copper, lead flotation and pyrite rougher flotation. Results show the effect of nitrogen on the promotion of pyrite.(tests 10-202,10-204)

	pyrite scavenger flotation			
	air		nitrogen	
	grade (%)	recovery (%)	grade (%)	recovery (%)
copper	0.18	0.56	0.08	6.7
lead	2.95	0.35	1.07	8.6
zinc	11.80	0.51	4.47	13.7
iron	26.60	0.41	41.04	45.7

So far, nitrogen has only been used to scavenge the pyrite not floated by a prior rougher flotation stage using air. Both rougher and scavenger pyrite concentrates were next floated solely in nitrogen.

Table 4.12 shows that the bulk copper, lead flotation results correspond to the results from standard bulk flotation tests. Again nitrogen promoted pyrite flotation leading to good grades and recoveries of iron. Some collector was needed, between 10 and 20 g/tonne of sodium isopropyl xanthate. Significant quantities of zinc again floated with the pyrite concentrate.

TABLE 4.12: Standard flotation of a copper, lead concentrate in air,then pyrite flotation in nitrogen, mean result from tests 10-204 and 10-213.

metal	bulk flotation		pyrite flotation	
	grade (%)	recovery (%)	grade (%)	recovery (%)
copper	1.28	74.8	0.11	13.4
lead	11.90	66.5	1.88	24.3
zinc	7.98	17.6	5.95	29.3
iron	29.24	20.7	39.38	64.3

The effect of removing the pyrite concentrate on zinc flotation selectivity is now considered. Figure 4.4 shows the grade of zinc concentrate floated as a function of zinc recovery, based on the zinc flotation feed. The zinc flotation characteristics of, first, the test including prior pyrite removal using nitrogen and, second, the standard test are highlighted. It indicates that by selectively removing the pyrite, the selectivity of the subsequent zinc flotation stage is improved.

The recovery of zinc is, however, limited by the prior misdirection of zinc to the bulk copper, lead and pyrite concentrates, as shown by the zinc recovery vs time curve illustrated by Figure 4.5. The 40% zinc concentrate was floated at a recovery of 54% based on plant feed, indicating an improvement of 15% in the zinc grade but at a cost of 17% in zinc recovery to the pyrite concentrate. The grade of iron in the zinc concentrate dropped from 20% to 12%. The next section addresses the problem of zinc loss to the pyrite concentrate.

4.1.5 Reducing the amount of zinc lost to the pyrite concentrate.

Results from the previous tests have shown that high grade pyrite concentrates can be floated from Brunswick Mining ore with minimal amounts of collector added. Copper activation and xanthate flotation of the pyrite flotation tails then yields a zinc concentrate of higher grade than is achieved through the conventional route.

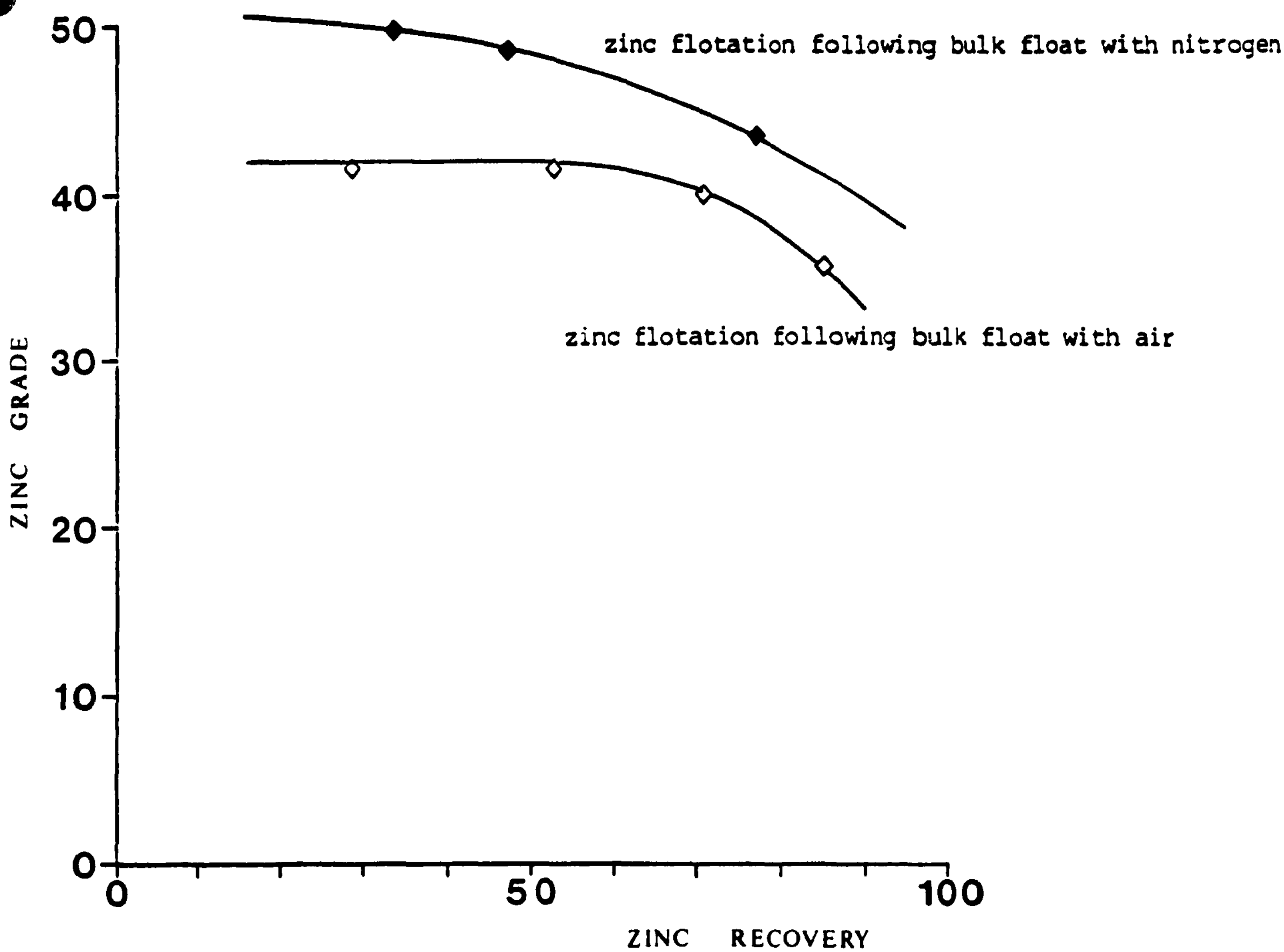


FIGURE 4.4 - Effect of removing the pyrite through nitrogen flotation on ensuing zinc flotation.

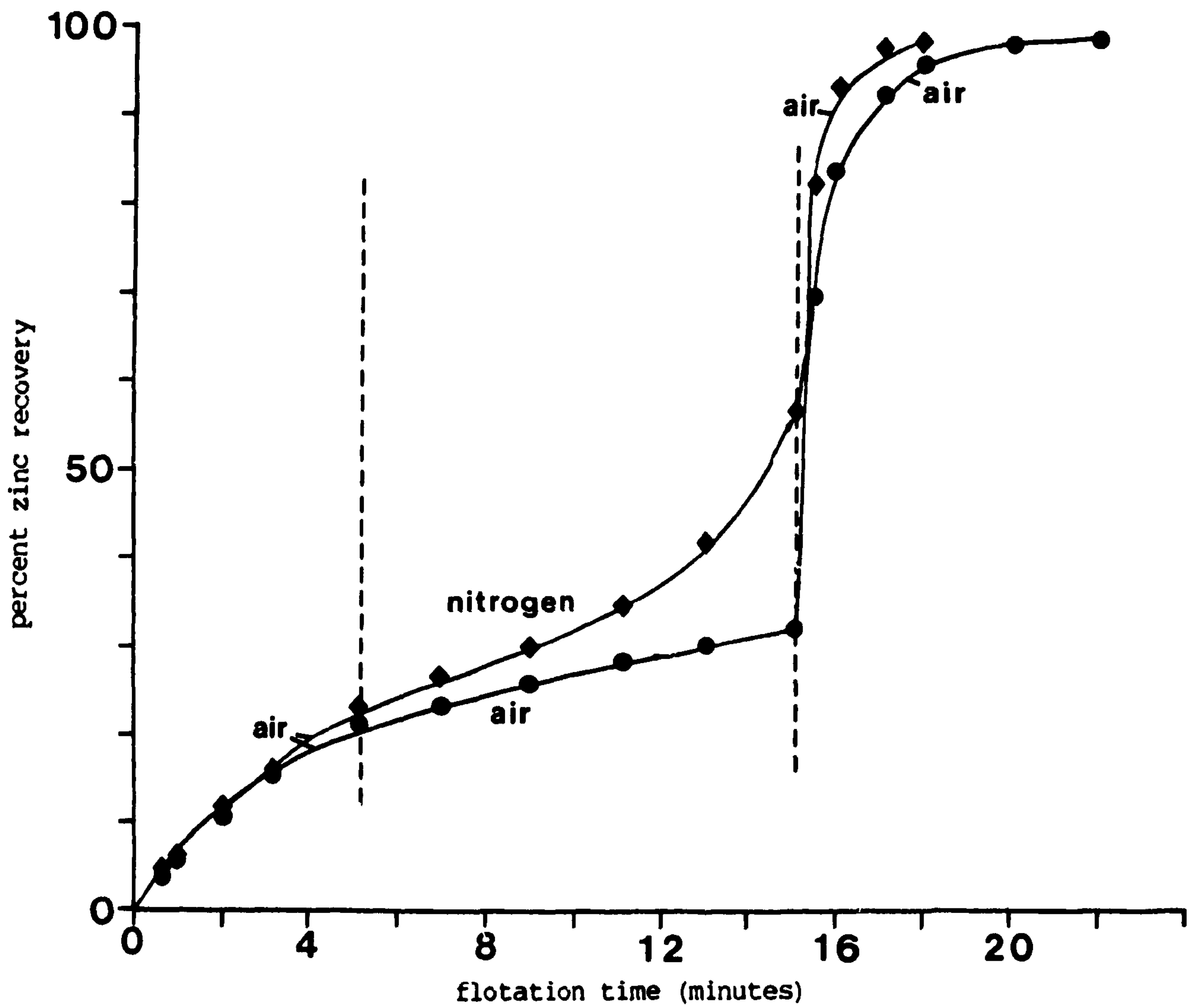


FIGURE 4.5 - Plot of zinc recovery against flotation time showing the effect of nitrogen flotation on zinc recovery to the pyrite concentrate, B.M.S. ore.

The chief metallurgical problem with the process is the loss of zinc that is associated with the pyrite concentrate. Limiting the loss of zinc to the pyrite concentrate and/or recovering it from the pyrite concentrate is fundamental to the economic viability of the proposed treatment route using nitrogen recovery of pyrite.

The work identified two ways to minimise this loss of zinc:

* Minimising collector addition in nitrogen flotation of pyrite.
* Floating the zinc from the pyrite concentrate through copper activation and reverse flotation in air.

Table 4.13 correlates the amount of collector added during nitrogen flotation, with the recovery of zinc and iron to the pyrite concentrate. Zinc flotation to the pyrite concentrate can be limited by using as little collector as possible during pyrite flotation. It also shows that at less than 10-20 g/tonne collection addition, the amount of pyrite floated is greatly reduced. Therefore 10-20 g/tonne is the optimum addition rate.

TABLE 4.13: The effect of collector dosage rate on the amount of zinc and iron reporting to the pyrite concentrate during nitrogen flotation.

test number	collector dosage rate (g/t)	iron recovery (%)	zinc recovery (%)
10-201	nil	46	13
10-203	10	37	17
10-204	10	51	17
10-501	20	61	23
10-213	20	65	32
10-209	80	80	34
10-210	80	76	39
10-211	100	80	38

Following flotation in nitrogen, the pyrite concentrate is repulped and the pH adjusted to 10.5. Copper ions are added to activate the sphalerite and after 5 minutes conditioning with air xanthate collector is added. A reverse zinc concentrate is then floated in air, the air serving to depress the pyrite. The recovery of zinc to the reverse concentrate is variable, probably being sensitive to conditions not fully understood as yet. In tests at McGill University, the amount of zinc recovered from the pyrite concentrate has been limited (see Table 4.14). Tests on-site at Brunswick Mining achieved significantly better recoveries of zinc as described in the next section.

Pyrite remains depressed during reverse zinc flotation, the recovery of iron being only 3.0%. However starvation quantities of xanthate (10-20 g/tonne) must be used in the pyrite flotation stage to ensure pyrite depression at this stage. While no results are reported here, it was observed that pyrite floated in nitrogen using higher collector addition could not be depressed in the reverse flotation stage.

TABLE 4.14: Metallurgical balance from zinc reverse flotation in air (test at McGill University).

(Sequence - Standard bulk copper, lead flotation; pyrite flotation in nitrogen; pyrite tails to zinc rougher, pyrite concentrate to zinc reverse flotation)

test	10-213			
product	pyrite final conc.		zinc reverse conc.	
	grade/recovery*		grade/recovery*	
	(%)	(%)	(%)	(%)
copper	0.11	87.8	0.21	12.2
lead	1.48	92.1	1.73	7.9
zinc	4.86	63.5	39.26	36.5
iron	40.50	97.0	17.33	3.0

* note: recoveries based on reverse flotation feed.

4.1.6 Tests performed on-site at the #12 plant, Brunswick Mining & Smelting.

This section was designed to check for any effects on nitrogen flotation of differences in procedure, water type etc. between the standard McGill flotation procedure and the standard Brunswick procedure.

The fundamental difference between the two procedures is the use of zinc sulphate in the grind at McGill University, as against sulphur dioxide. The testwork repeated some of the work already performed, notably comparing the floatability of pyrite in air and in nitrogen, and then checked the effectiveness of the reverse flotation step on the pyrite concentrate.

Bulk flotation results are similar to those using the standard McGill procedure. 81% of the lead floated at a grade of 14.7% and 74% of the copper floated at a grade of 1.0%. Once again pyrite flotation in air was ineffective, recovering 12% of the iron based on the mill feed, at a grade of 39%.

Pyrite flotation in nitrogen was successful. The nitrogen activated the pyrite, leading to an iron recovery of 53%. The froth was, however, visibly more brittle using the Wemco cell at Brunswick Mining than was the case with the tests using the Leeds cell at McGill University. As a result the froths were shallower and permitted more zinc to be carried over with the pyrite. The zinc grade of the pyrite concentrate was 6-8%.

Loss of zinc to the pyrite concentrate is reflected in its low recovery to the zinc concentrate. At first sight the zinc grade (32%) is also low, but closer inspection of the results reveals this is because recovery is high (97% of the zinc in the zinc flotation feed is recovered to the concentrate). Figure 4.6 shows the concentrate grade achieved as a function of zinc recovery, based on zinc flotation feed. This is compared with the same relationship from a standard test at McGill, and shows that the results correspond with those described earlier.

Zinc reporting to the pyrite concentrate was readily recovered through reverse flotation under the conditions prevailing at Brunswick Mining. A pyrite concentrate, floated in nitrogen following standard copper, lead bulk flotation, was cleaned through reverse flotation of the zinc in air. A zinc concentrate containing 32% zinc was floated, recovering more than 70% of the zinc from the pyrite concentrate as outlined in Table 4.16.

TABLE 4.16: Metallurgical balance from the reverse flotation of zinc from the pyrite concentrate.

(Sequence - Standard bulk copper, lead flotation; pyrite flotation in nitrogen; pyrite tails to zinc rougher, pyrite concentrate to zinc reverse flotation,)

test 10-403

product	pyrite final conc. grade/recovery		zinc reverse conc. grade/recovery	
	(%)	(%)	(%)	(%)
copper	0.12	84.0	0.14	16.0
lead	1.20	79.2	1.93	20.8
zinc	2.14	28.8	32.37	71.2
iron	42.72	92.2	22.05	7.8

* note: recoveries based on reverse flotation feed.

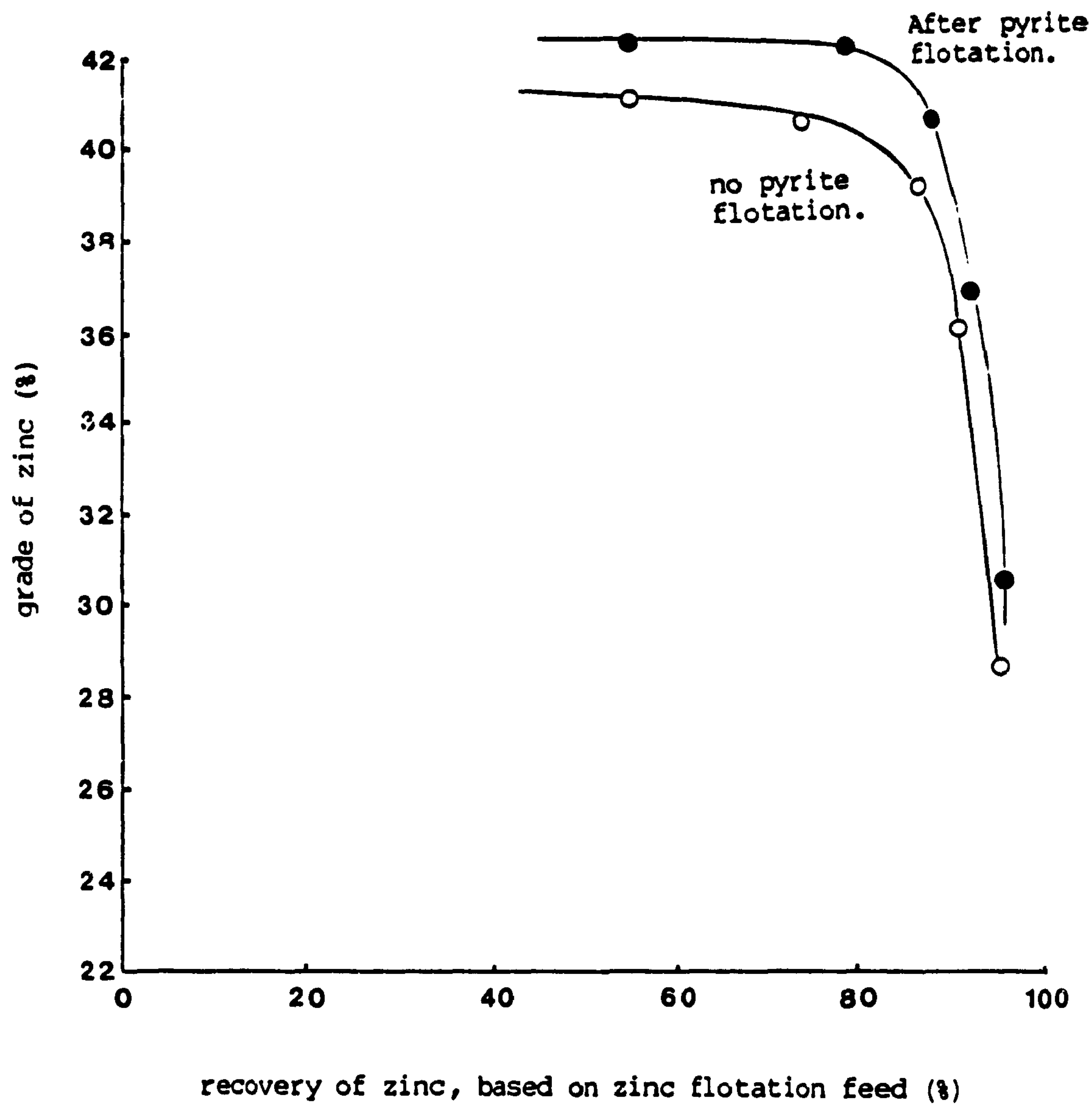


FIGURE 4.6 - Effect of prior removal of pyrite on the grade/recovery relationship from zinc flotation. (Brunswick Mining ore)

The metallurgical balance for this test is summarised by Figure 4.7, which in turn is compared with the conventional route in the next section.

4.1.7 Summary of the metallurgy achieved through pyrite flotation with nitrogen and zinc reverse flotation using air.

Figure 4.7 summarises the results achieved in these tests from the use of the proposed process on Brunswick Mining ore. It shows that zinc rougher flotation achieves a grade of 38% at 67% recovery. This is considerably better than the grade of 25% at 72% recovery, achieved through the conventional route. An overall comparison of results is illustrated in Table 4.17:

TABLE 4.17: Iron and zinc metallurgy data from the proposed treatment route using flotation of the pyrite concentrate and zinc reverse flotation, compared with the conventional route.

	proposed route		conventional route	
	Fe	Zn	Fe	Zn
Bulk flotation				
grade(%)	29.7	9.5	33.8	7.6
recovery(%)	24.1	23.2	27.8	21.7
Pyrite flotation				
grade(%)	42.7	2.1	-	-
recovery(%)	40.4	6.1	-	-
Zinc flotation				
grade(%)	15.8	38.4	20.5	25.1
recovery(%)	9.2	67.2	16.7	71.8
Final tails				
grade(%)	19.7	0.9	24.9	0.8
recovery(%)	26.3	3.5	55.5	6.5

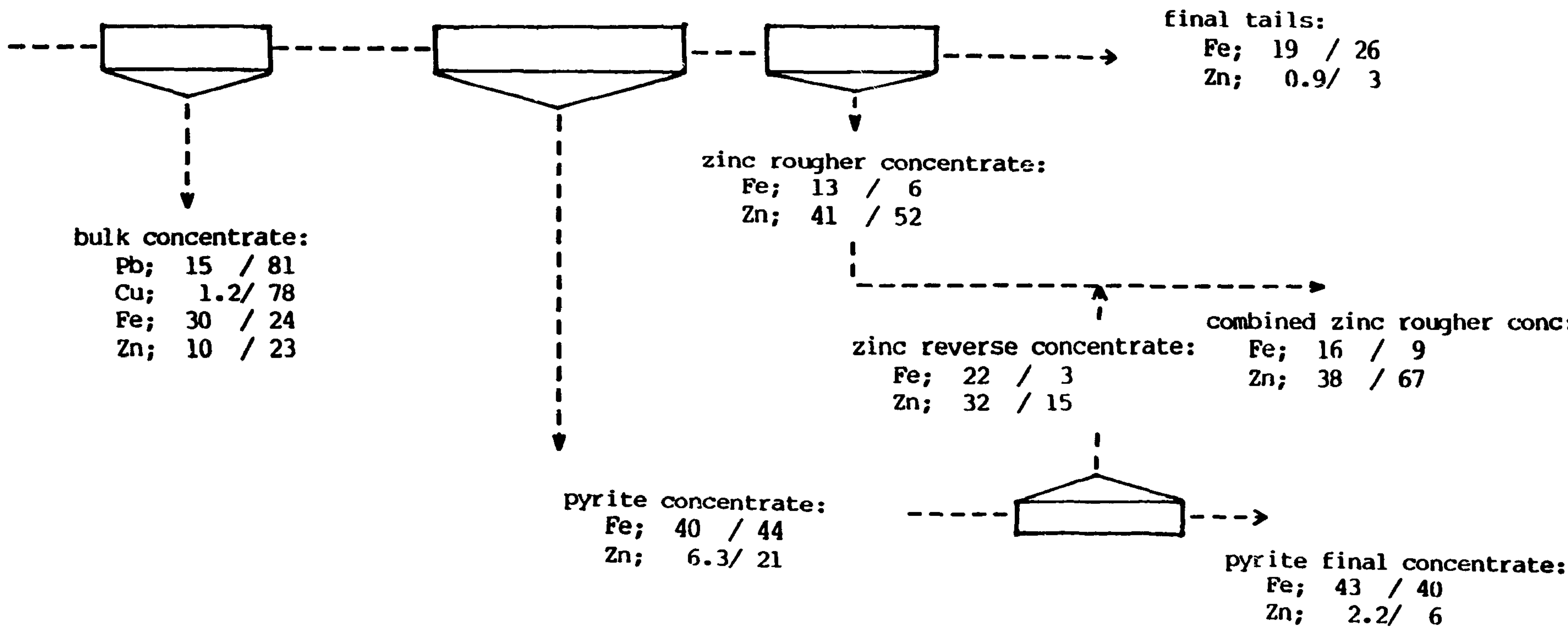


FIGURE 4.7 – Fe & Zn metallurgical balance from test including zinc reverse cleaning.

Labels illustrate: metal; % grade/ % recovery

4.1.8 Preliminary analysis of the chemistry of nitrogen flotation.

Nitrogen is an inert gas and is therefore not likely to play a chemically active role in the promotion of pyrite. To confirm this argon was used in the place of nitrogen. Test 10-501 represents one result from this work. It shows that argon also promoted the flotation of pyrite, 60% of the iron being recovered using 20 g/tonne of xanthate, at a grade of 38% iron.

Some zinc was again floated off the pyrite concentrate, producing a 33% zinc concentrate at 26% zinc recovery. The results are therefore similar to those achieved at McGill University using nitrogen, indicating that pyrite flotation in argon follows the same mechanism as in nitrogen. This confirms that nitrogen plays no direct role in the promotion of pyrite flotation.

The promotion of pyrite flotation is unlikely to be potential related. Pulp potential should fall with the use of nitrogen, which should depress pyrite, according to current electrochemical knowledge of flotation. Figures 4.8 and 4.9 show how pulp potential varies with iron recovery during flotation tests using air and nitrogen during the pyrite flotation stage. Nitrogen slowly drops the pulp potential while at the same time promoting pyrite flotation. The rate at which the pulp potential drops is slow, dropping less than 100mV throughout the 25 minutes of nitrogen conditioning and flotation. Its effect is small in comparison to the effect of copper sulphate or variations in the pH.

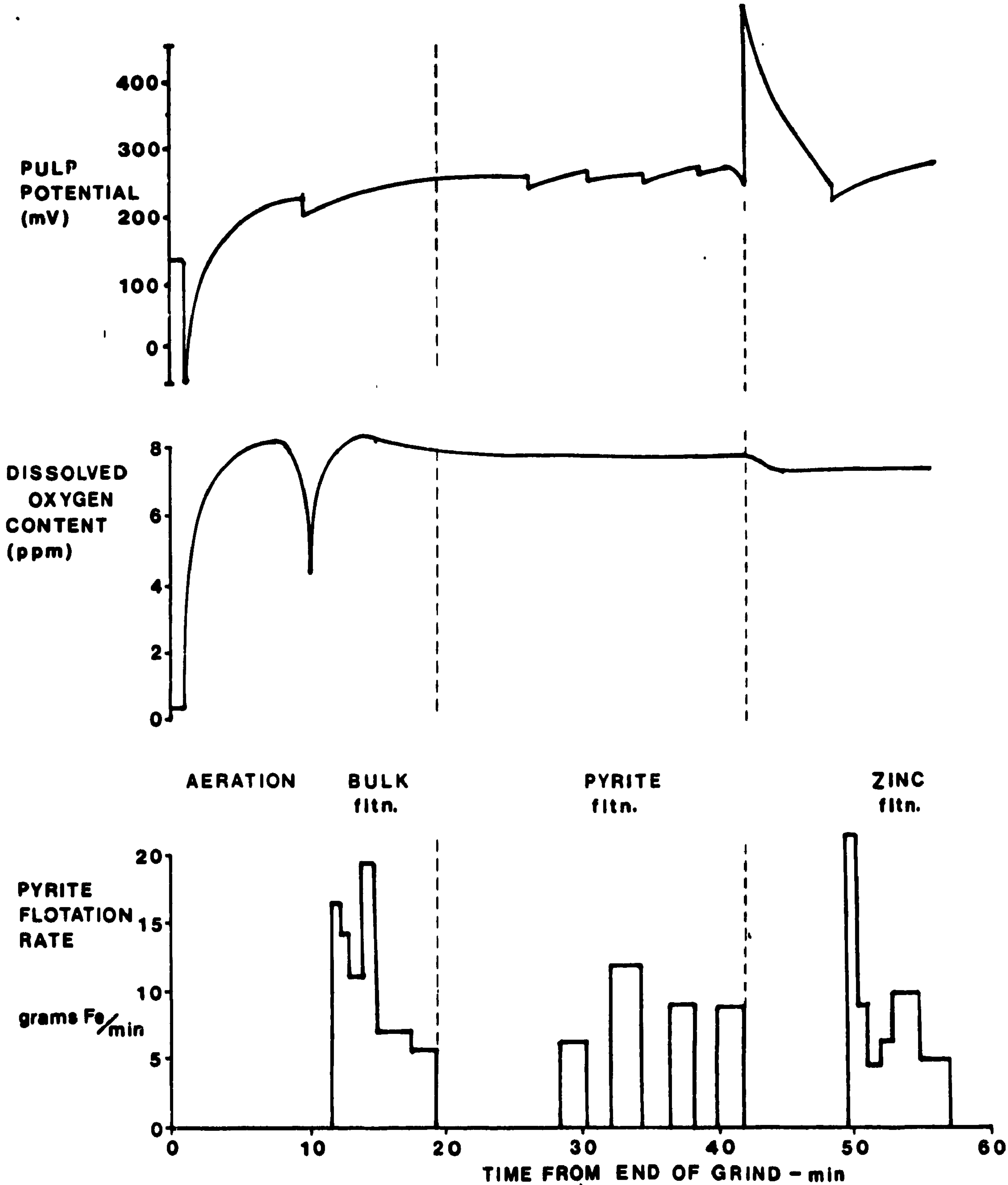


FIGURE 4.8: variation of pulp potential, dissolved oxygen content and pyrite flotability through test including bulk, pyrite and zinc flotation in air.

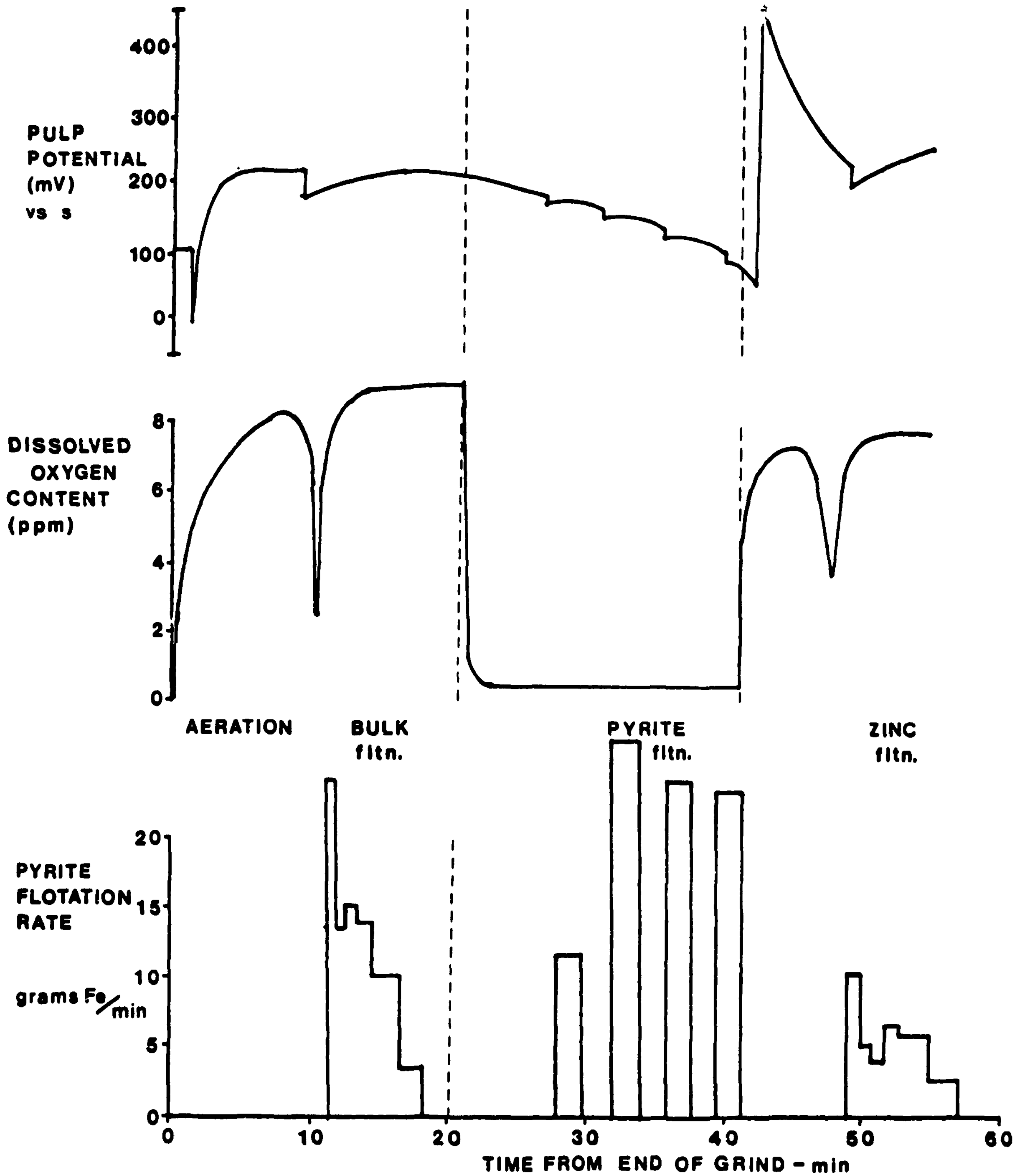


FIGURE 4.9 : as figure 4.8 except pyrite flotation is in nitrogen.

4.2 FLOTATION TESTWORK ON MATTABI MINES ORE

Unlike at Brunswick Mining, zinc flotation does not pose any serious problems at Mattabi. However, copper,lead bulk flotation and subsequent separation are difficult. This testwork describes the effect of collectorless flotation on the ore, and assesses the effect of varying the collector dosage rate. Some work examining the effects of sulphite ions and nitrogen on pyrite flotation is included.

Results show that:

* collectorless flotation recovers more than 80% of the chalcopyrite and 40% of the galena, while rejecting 90% of the pyrite and sphalerite.

* Sulphite ions aid pyrite rejection from a bulk concentrate floated with collector.

* Nitrogen promotes pyrite flotation although its effect is limited by the presence of sulphite ions.

Tests performed recently in the laboratory (56) have confirmed some of the observations made above. Some results from these tests, performed on ore from Mattabi's Lyon Lake deposit are included in this report.

4.2.1 Development of standard conditions.

Consistent selective flotation of a copper, lead concentrate proved difficult and the combined copper/lead grade in the concentrate (see Table 4.18) never exceeded 14%. This is lower than the 25% normally achieved on the plant. The lower copper, lead bulk concentrate grades were due to flotation of excess pyrite.

TABLE 4.18: Comparison of the grade/recovery characteristics of copper, lead, zinc and iron from the flotation of the bulk copper, lead concentrate during Test 11-103 and at Mattabi mines.

	Copper/lead bulk rougher			
	Lab.standard		plant data	
	grade/ (%)	recovery (%)	grade/ (%)	recovery (%)
copper	7.80/	70.4	13.00/	75.0
lead	6.79/	55.8	12.00/	75.0
zinc	11.63/	7.2	10.00/	3.4
iron	26.38/	5.4	15.55/	1.8

Zinc flotation results from the laboratory tests were more consistent with plant performance (see Table 4.19). They also show that sphalerite can be floated quite effectively from the pyrite.

TABLE 4.19: Comparison of metal grades and recoveries, zinc flotation in test 11-103 and on the plant at Mattabi Mines.

	zinc rougher concentrate			
	test 11-103		plant data	
	grade/ (%)	recovery (%)	grade/ (%)	recovery (%)
copper	0.55/	17.0	0.40/	14.5
lead	1.10/	30.9	0.40/	15.8
zinc	42.43/	90.4	43.00/	92.7
iron	14.98/	10.6	15.70/	11.3

The standard tests reflect the metallurgical problems experienced processing Mattabi ore on production scale. Bulk copper,lead flotation generally yielded poor combined copper,lead grades. Zinc flotation however produced good grades and recoveries.

The testwork, therefore, concentrated on the problems associated with copper and lead flotation, while also assessing the ability of nitrogen to promote pyrite flotation.

4.2.2 The effect of collector on the characteristics of copper, lead bulk flotation of Mattabi ore.

In test 11-301 a collectorless concentrate was floated after grinding. High recovery of chalcopyrite was achieved (85%) while only 45% of the galena was floated as illustrated by Figure 4.10. Little flotation of sphalerite and pyrite was observed.

Following-up these results, M. Leroux at McGill University (56) has recently tested collectorless flotation on ore from the Lyon Lake deposit, now being mined by Mattabi Mines Ltd. Once again collectorless flotation recovers more than 80% of the copper

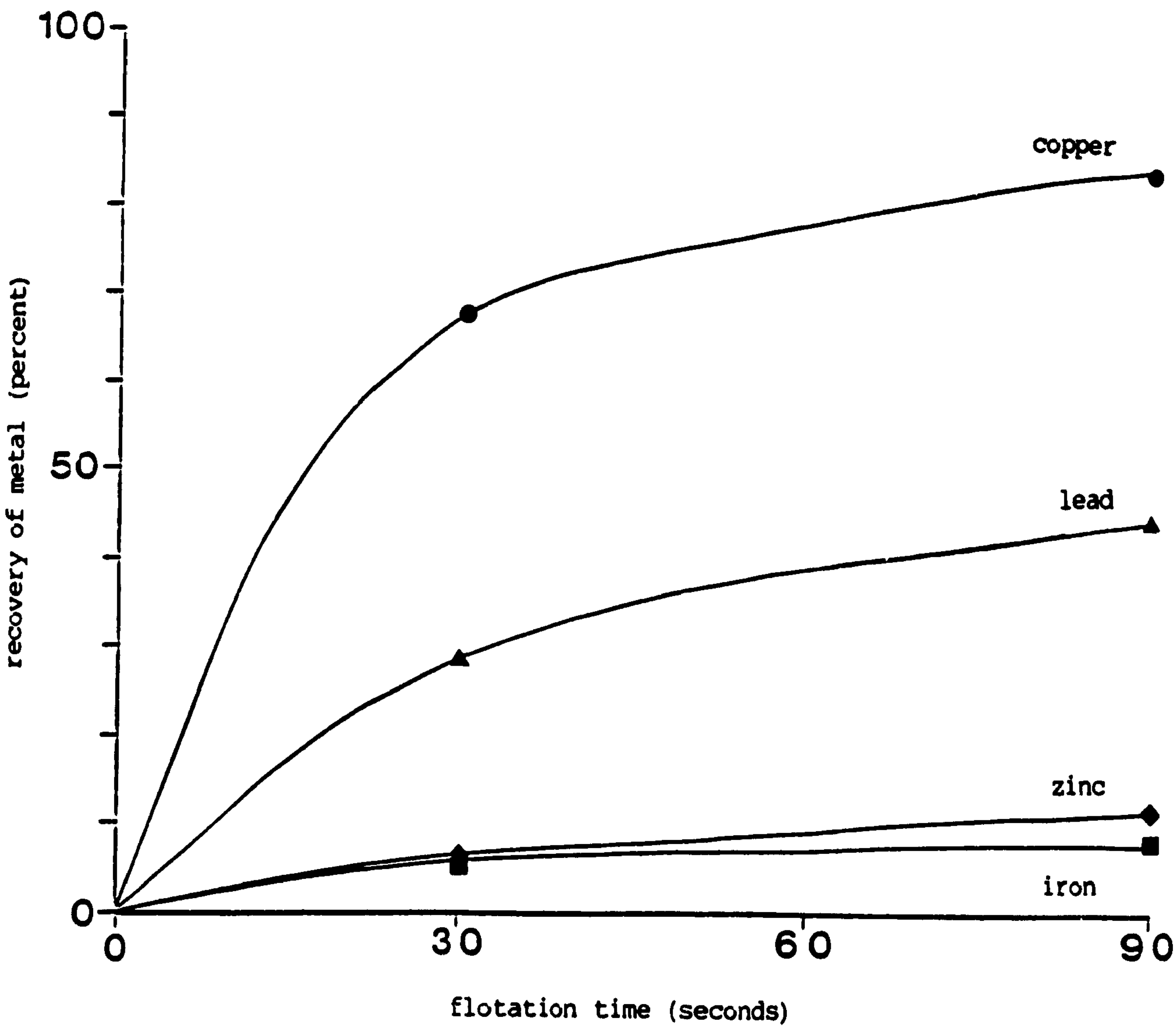


FIGURE 4.10 - Collectorless bulk flotation. Recoveries of Cu, Pb, Zn and Fe against flotation time.

minerals, while recovering 60% of the galena. Pyrite and sphalerite did not respond to collectorless flotation, and the resulting copper,lead combined grade was superior to that using collector. The respective copper rougher grade-recovery relationships for flotation with and without collector are illustrated by Figure 4.11.

The same series of tests revealed that collectorless flotation using nitrogen also recovered almost 90% of the copper minerals. The use of nitrogen appeared to reduce the flotation recovery of galena (see Figure 4.12).

At 5 g/tonne xanthate addition, the recovery of galena was raised to 76%, that of copper, iron and zinc sulphides remaining virtually unchanged (Figure 4.13). At 40 g/tonne xanthate collection the recoveries of iron and zinc sulphides begin to rise (Figure 4.14).

4.2.3 Nitrogen flotation of Mattabi ore

In Test 11-204, 20 minutes nitrogen conditioning preceded bulk flotation in nitrogen. Zinc sulphate was added to the mill at pH 9.5 as the pyrite/sphalerite depressant. A bulk concentrate containing 44% iron at 84% Fe recovery was floated. The bulk flotation iron grade/recovery relationship is illustrated by Figure 4.15.

Under identical conditions, pyrite flotation in air (Test 11-203) is much less effective. Table 4.20 compares the two results:

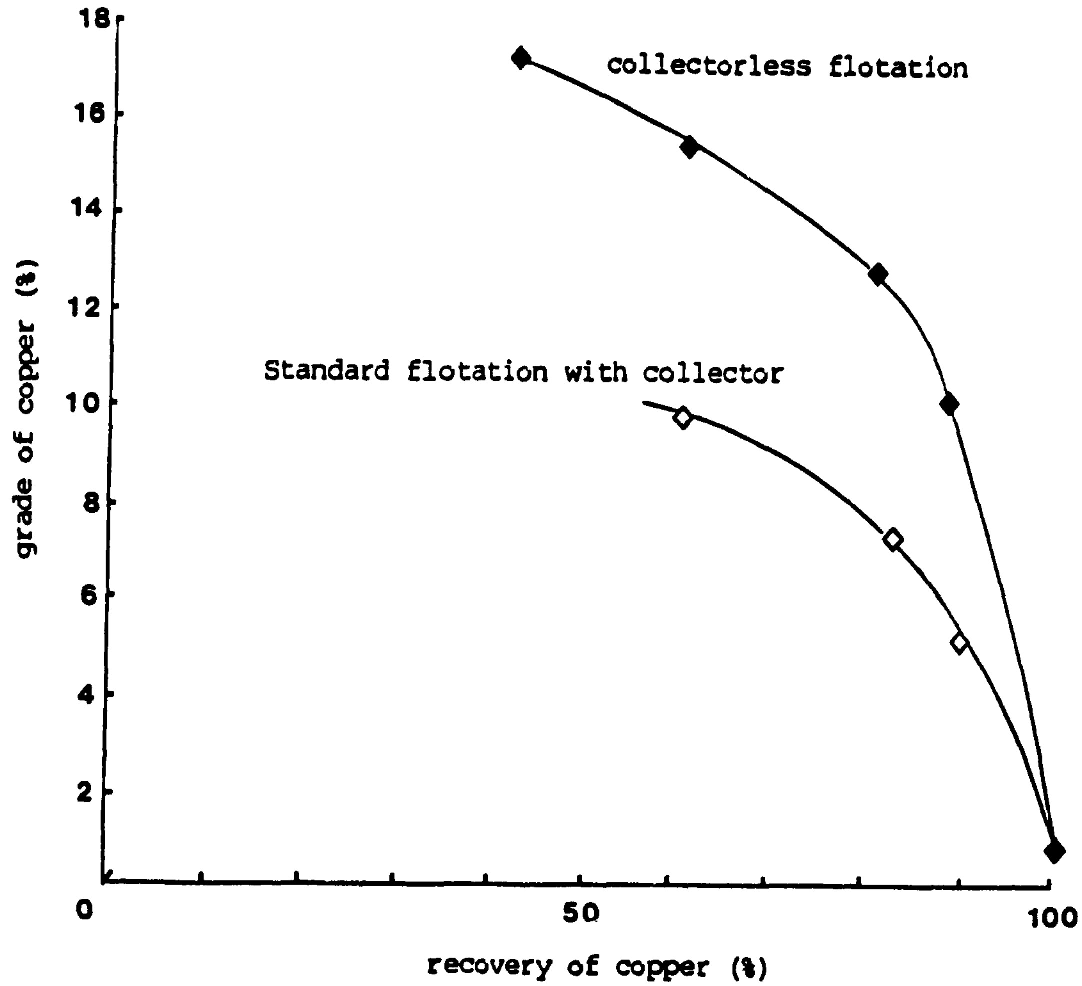


FIGURE 4.11 - Comparison of copper rougher grades and recoveries achieved through collectorless and standard flotation tests at McGill University. Lyon Lake ore.

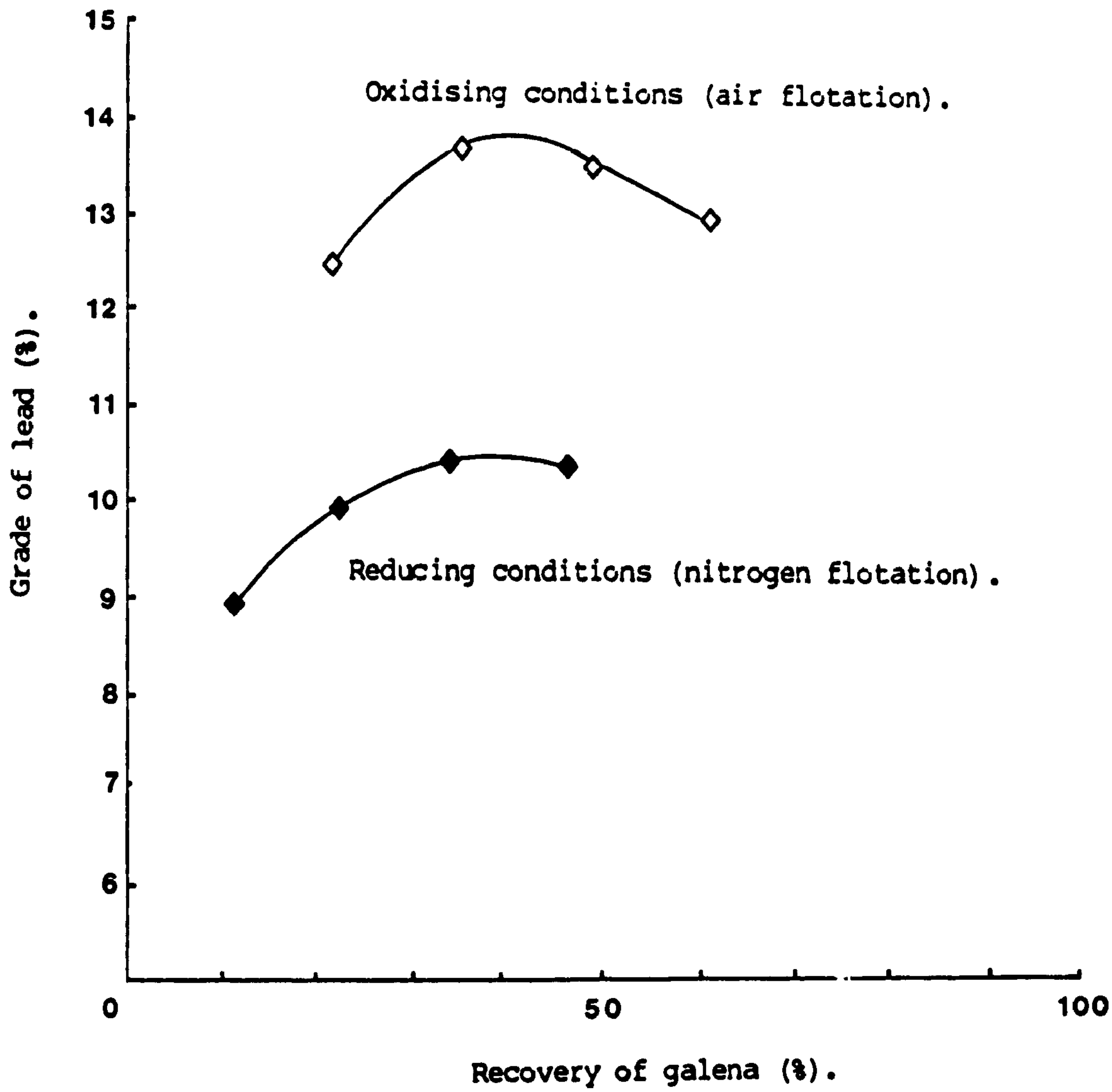


FIGURE 4.12 - Comparison of the effect of oxidising and reducing conditions on the collectorless flotation of galena from Lyon Lake ore.

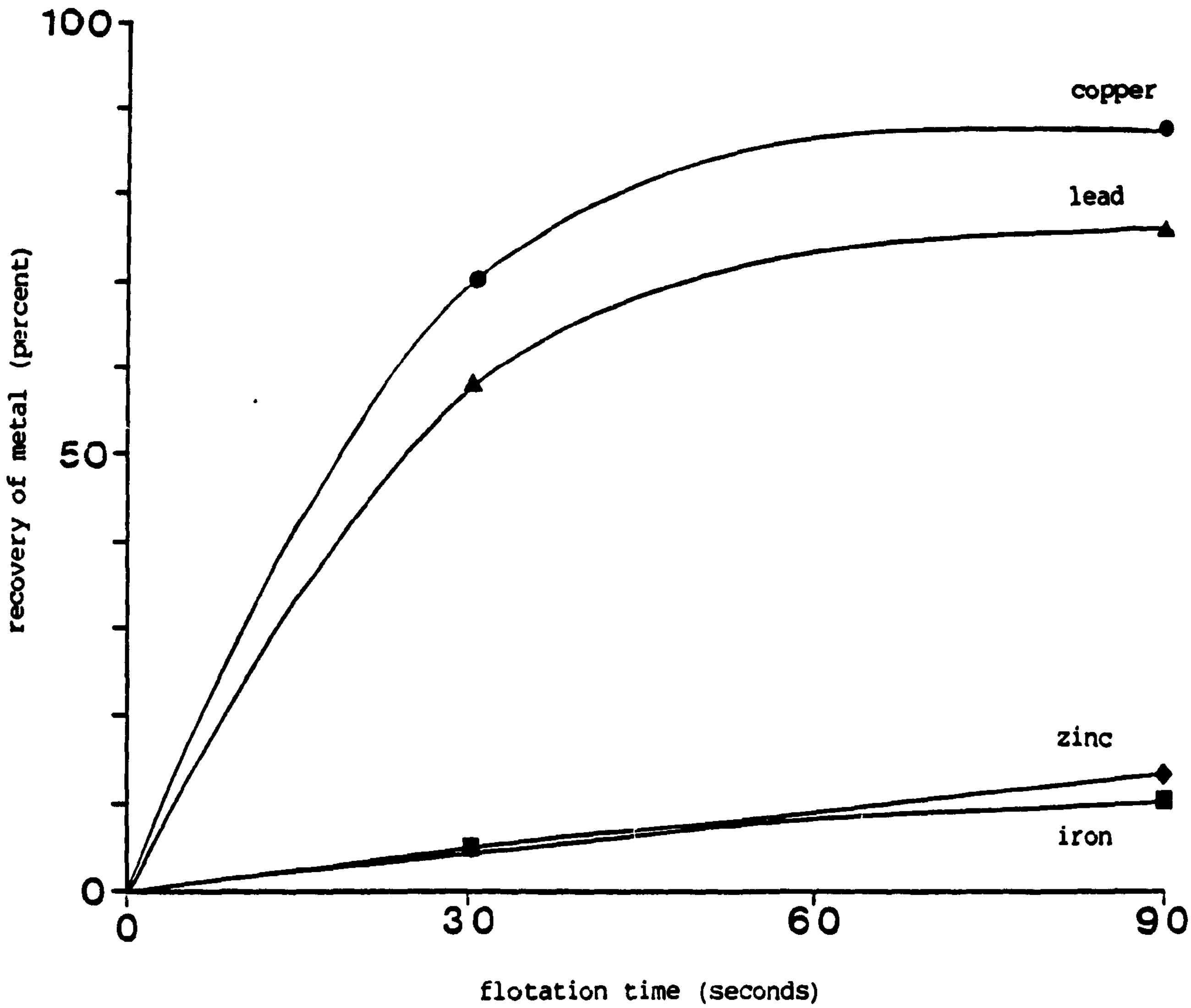


FIGURE 4.13 - Bulk flotation using 5 g/t collector (combination cyanamid 325/241). Recoveries of Cu, Pb, Zn, Fe against flotation time.

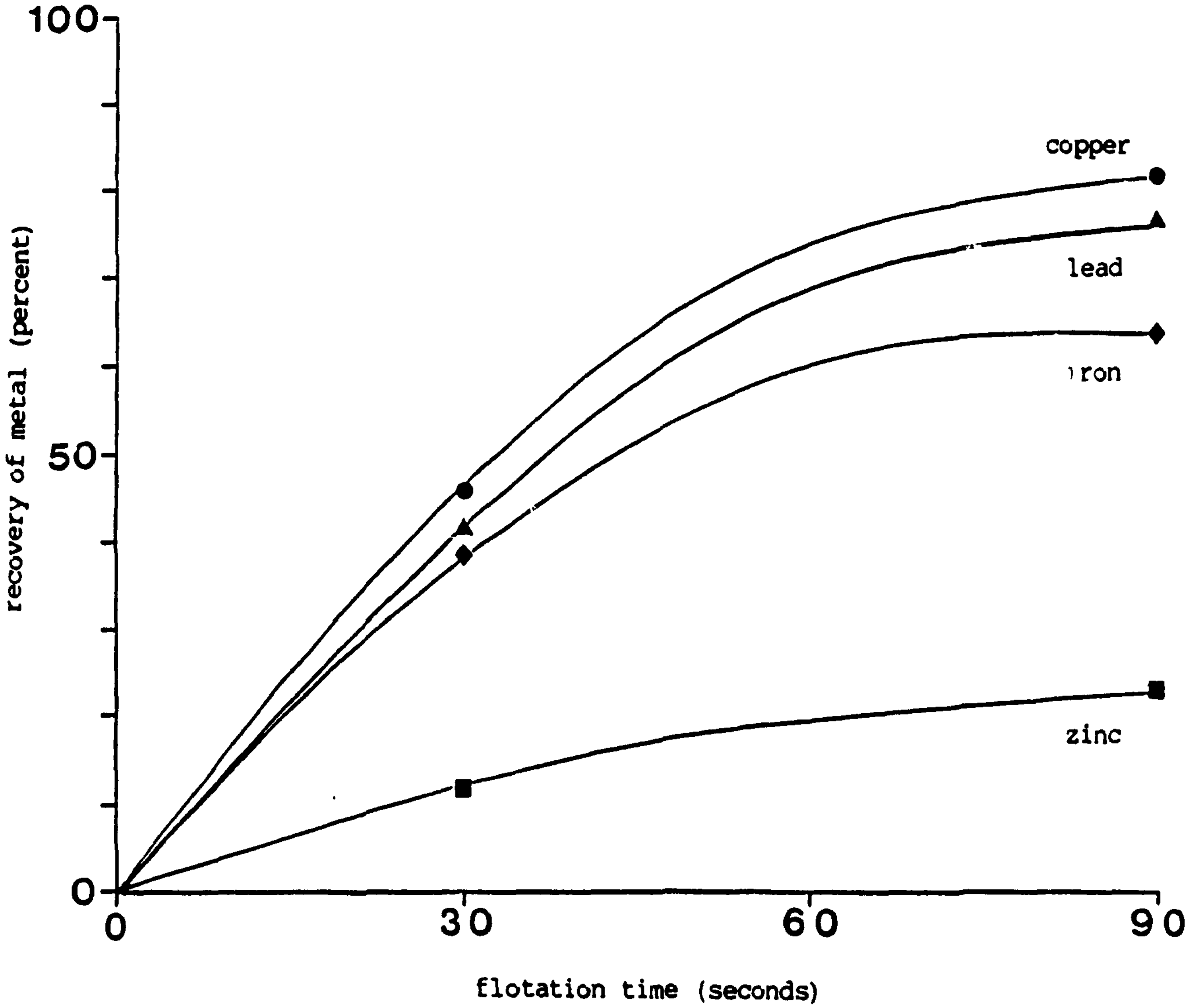


FIGURE 4.14 - Bulk flotation using 40 g/t collector (combination cyanamid 325/241). Recoveries of Cu, Pb, Zn, Fe against flotation time.

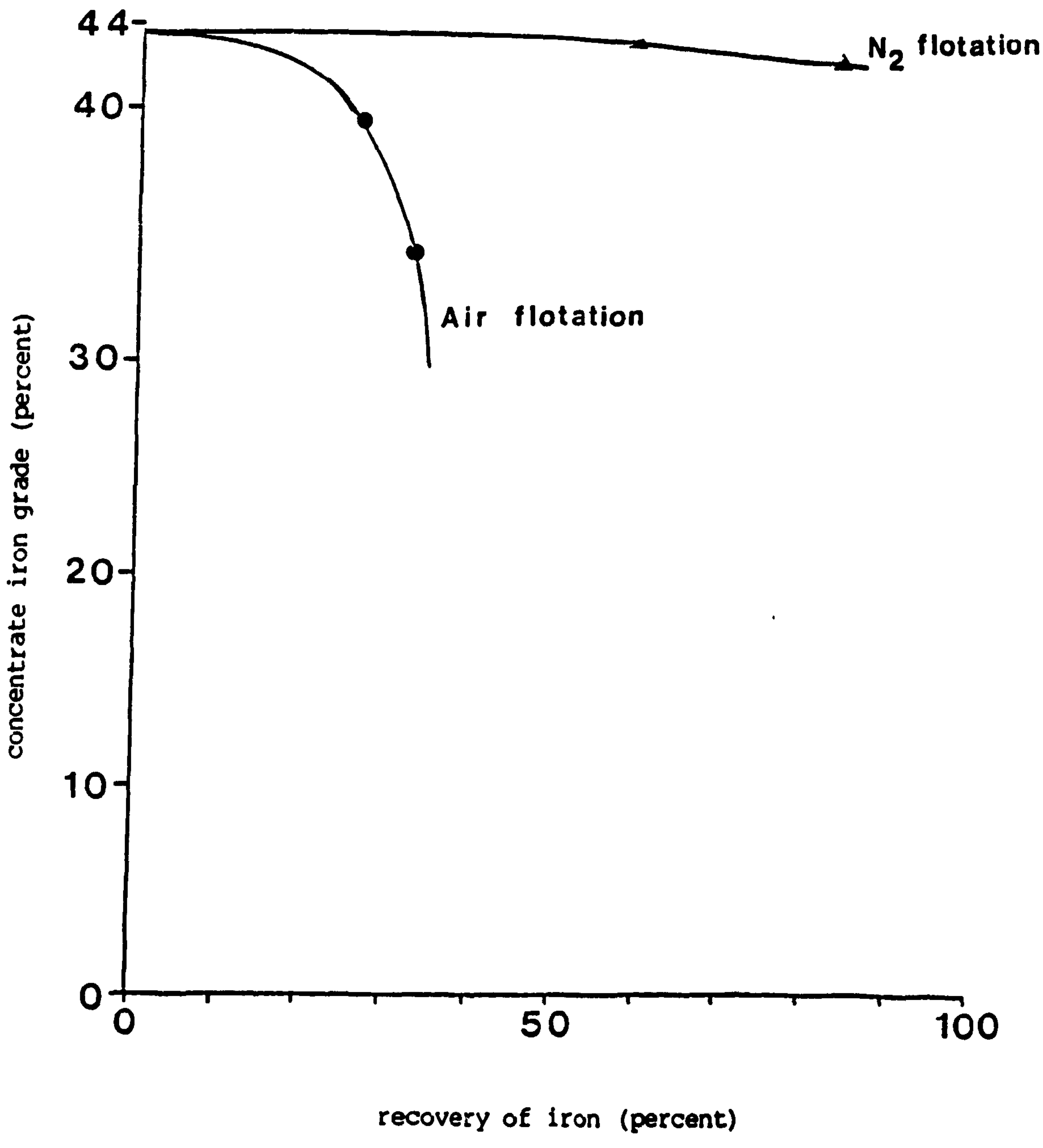


FIGURE 4.15 - Effect of nitrogen on the flotation of pyrite. Grade/recovery relationship of pyrite in Fe/Cu/Pb bulk flotation.

TABLE 4.20: Comparison of results from standard copper, lead flotation using nitrogen and air as the gas phase in flotation.

	Copper/lead bulk rougher			
	using nitrogen		using air	
	grade/ (%)	recovery (%)	grade/ (%)	recovery (%)
copper	0.63/	52.9	2.29/	84.0
lead	0.75/	61.2	1.84/	62.8
zinc	2.15/	11.9	4.77/	11.9
iron	44.24/	83.8	40.22/	33.7

Copper recovery to the bulk concentrate was reduced during nitrogen flotation as illustrated in Table 4.20. Lead and zinc recoveries were unaffected and pyrite recovery more than doubled. This result confirms the observations made during Brunswick Mining testwork that nitrogen can promote the flotation of pyrite.

The use of zinc sulphate as a zinc depressant, maintained as standard for tests at McGill University, resulted in very poor copper,lead grades in the bulk concentrate. Combined copper,lead grades were 4-6% despite recoveries of 55-85% as a result of relatively strong flotation of pyrite. A typical example of this is illustrated by Table 4.20.

Sodium sulphite was much more effective at reducing pyrite flotation and led to copper,lead combined grades closer to (but still lower than) those obtained on the plant as illustrated by Test 11-103 (Table 4.18). Combined copper/lead grades rose to 10-14% at similar (55-85%) recoveries. Figures 4.16 and 4.17 illustrate more clearly the effect of sodium sulphite on pyrite depression. In both cases excess xanthate was added to

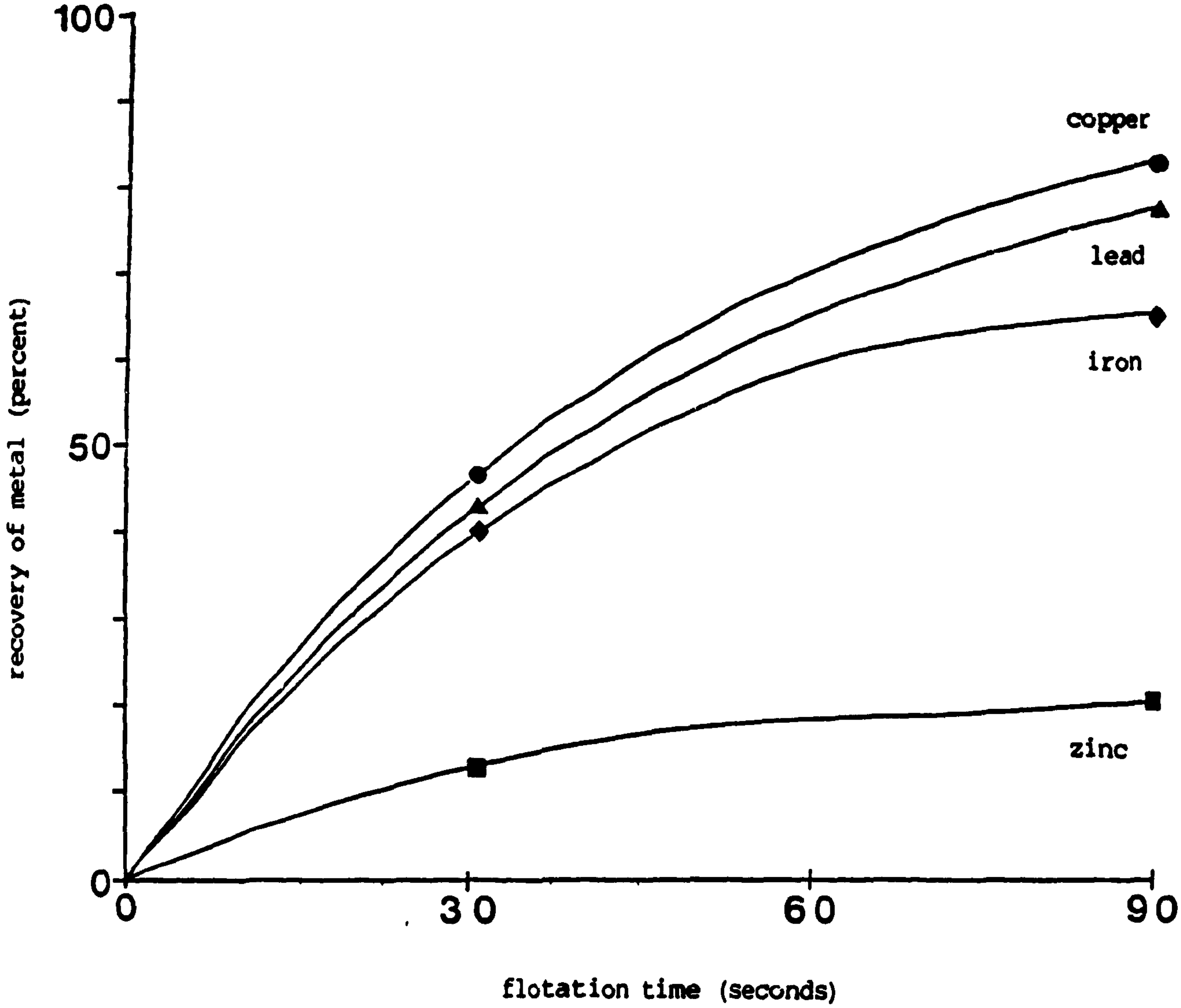


FIGURE 4.16 - Air flotation of Mattabi ore using 1000 g/t sodium sulphite in grind (bulk flotation only). 1000 g/t sodium sulphite is equivalent to 500 g/t SO2.

% Cu, Pb, Zn, Fe recoveries vs flotation time (sec) using excess collector (40 g/t)

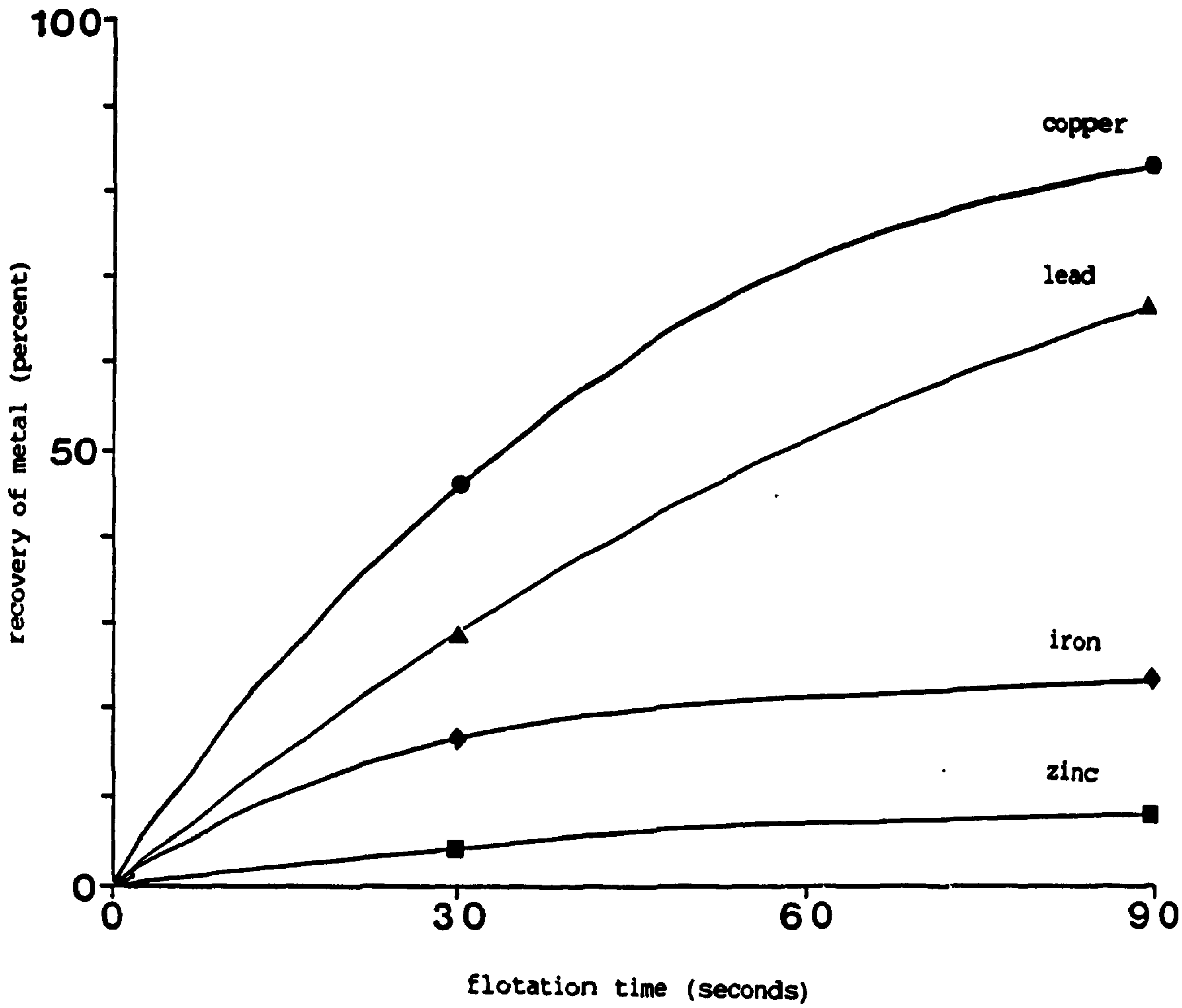


FIGURE 4.17 - Air flotation of Mattabi ore using 3000 g/t sodium sulphite in grind (bulk flotation only). 3000 g/t sodium sulphite is equal to 1500 g/t SO2.

% Cu, Pb, Zn, Fe recoveries vs flotation time (sec) using excess collector (40 g/t) deliberately float the pyrite and this led to a larger differential between recoveries. It is clear that sodium sulphite can strongly, and selectively depress pyrite.

Tests using sulphite ions in air flotation of Lyon Lake ore also showed that pyrite could be selectively depressed, this time at lower dosage rates.

The effect of sodium sulphite on nitrogen flotation of pyrite is complex. With sodium sulphite added to the mill, if bulk flotation is conducted in nitrogen, the recovery of pyrite is relatively low. However, if flotation is performed in air after nitrogen conditioning then significantly more pyrite is recovered. Table 4.21 summarises these results:

TABLE 4.21: Effect of nitrogen conditioning and flotation on the metal grade/recovery relationships of bulk copper, lead, iron flotation - after 1000 g/tonne sodium sulphite addition to the mill.

conditioning gas......	nitrogen		nitrogen		air	
flotation gas......	nitrogen		air		air	
	grade/recovery		grade/recovery		grade/recovery	
	(%)	(%)	(%)	(%)	(%)	(%)
copper	2.23/	53.8	1.85/	77.9	5.26/	88.1
lead	2.23/	58.5	1.55/	60.1	4.80/	76.0
zinc	6.05/	9.3	3.89/	11.1	11.60/	13.4
iron	37.99/	19.4	41.06/	39.6	28.77/	10.9

Maintaining a nitrogenated environment throughout seems, in this case, to depress both pyrite and chalcopyrite flotation. This is contrary to earlier results using zinc sulphate. However it does follow results from similar tests on Brunswick Mining ore, where nitrogen flotation without any air contact was found to be erratic. It therefore seems that under certain conditions nitrogen fails to promote pyrite flotation. The effect of sulphite addition and nitrogen on pyrite flotation is illustrated by Figure 4.18. This plots lines of equal pyrite recovery at varying levels of nitrogen conditioning and sulphite addition and shows that nitrogen is only effective when the sulphite addition rate is low.

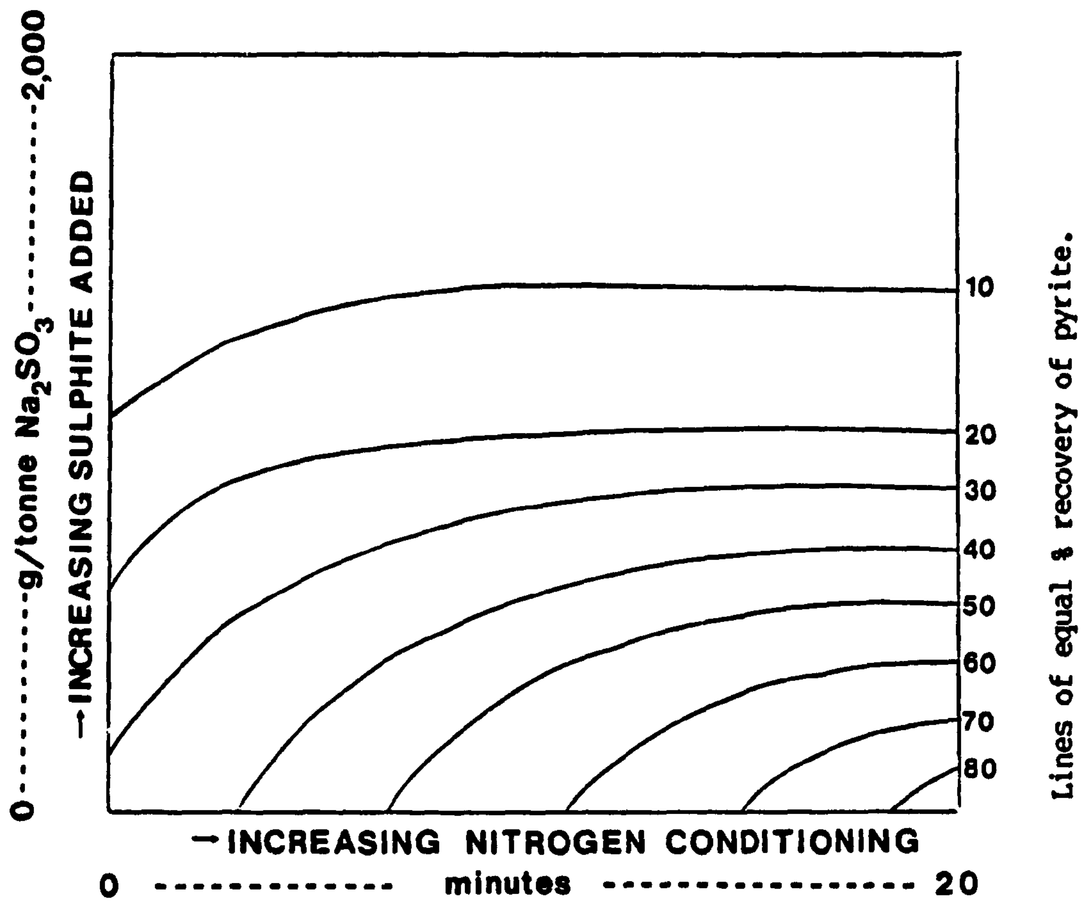


FIGURE 4.18 - Effects of nitrogen conditioning time and sulphite addition on the floatability of pyrite from Mattabi ore.

4.3 TESTWORK ON KIDD CREEK ORE

"D" division at Kidd Creek Mines treats a particularly difficult ore. Both copper and lead concentrates are low grade and pyrite reverse flotation is included in the zinc circuit to remove a highly floatable pyrite constituent.

With pyrite flotation already incorporated into the circuit, the potential use of nitrogen to promote pyrite flotation is of particular interest. Impure nitrogen is available locally so the effect of impure nitrogen was tested on the Kidd Creek ore.

All tests include a standard bulk copper,lead flotation stage followed by flotation of pyrite under different conditions, and finally the flotation of sphalerite in air. As with the Brunswick Mining tests, the presence of the bulk flotation stage prior to pyrite flotation helped to check the reproducibility of conditions such as ore, water and reagent quality, grind and flotation cell performance.

The test results included in this section show that gases with up to 5% oxygen still promote pyrite flotation.

4.3.1. Check on the reproducibility of conditions and comparison with plant results.

Figure 4.19 illustrates the copper and lead grade/recovery bands, during bulk flotation in the four tests reported. They show that the results from the four tests agree reasonably well, implying that flotation conditions remained the same throughout the testwork.

A significant loss of sphalerite to the bulk flotation concentrate was observed. The recovery of sphalerite to the bulk concentrate varied from 18% to 36% leading to zinc grades of 13.5% to 15% in the bulk concentrate. Pyrite flotation to the bulk concentrate was consistently 11-12% except for test 12-101 when it reached 19%. The iron grade was 24-25%.

In each case, the zinc flotation feed varied in composition so it is impossible to directly compare zinc flotation performance. In general, recoveries are low due to the mis-direction of zinc to bulk and pyrite flotation concentrates.

4.3.2. Effect of nitrogen content on the selective flotation of a pyrite concentrate.

Table 4.22 illustrates the effect of varying the nitrogen, or oxygen content of the flotation gas on pyrite recovery and the dissolved oxygen content in the pulp liquor.

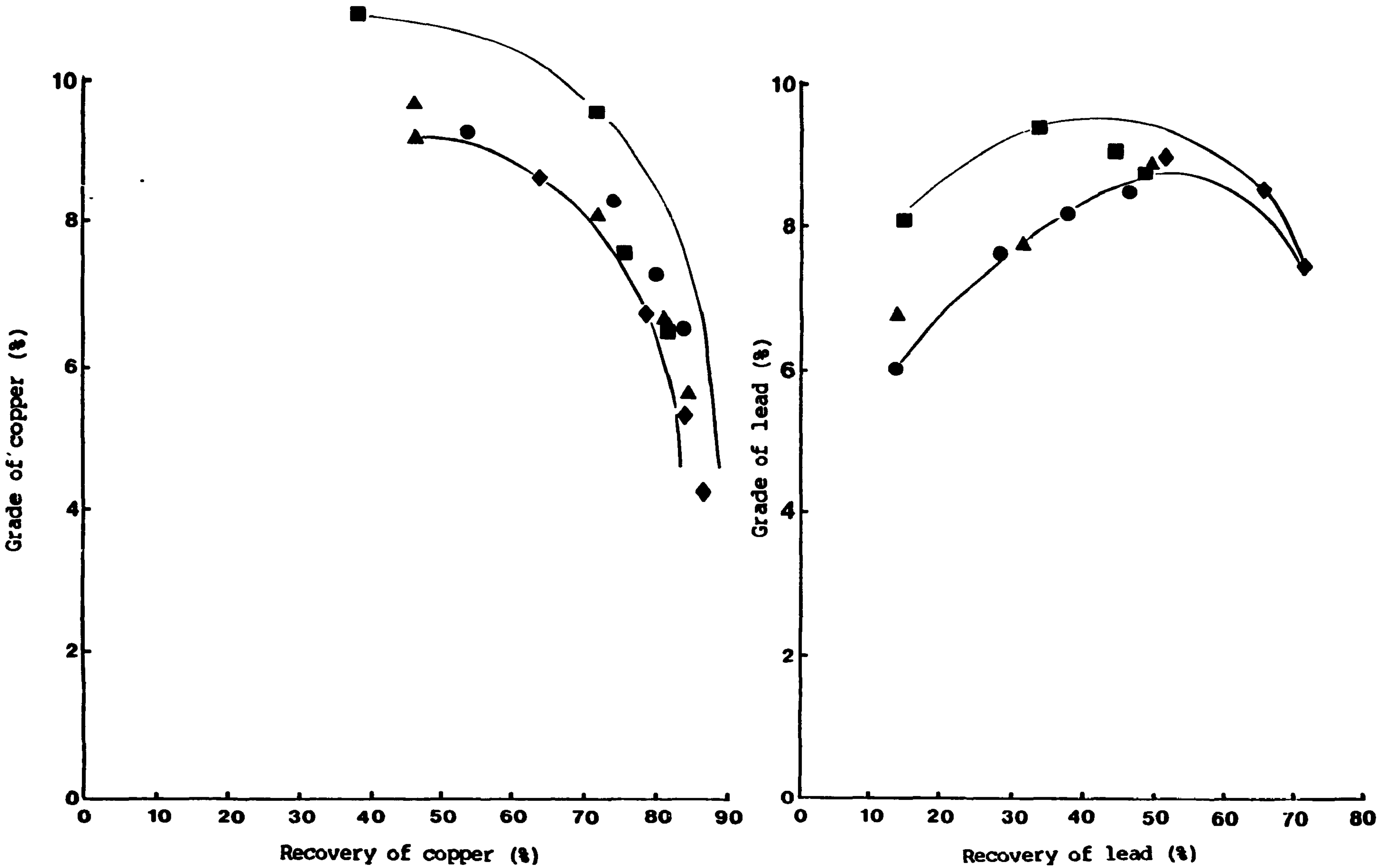


FIGURE 4.19 – Grade/recovery relationships for copper and lead flotation to the bulk concentrate. Graphs show copper floated before lead. (Kidd Creek Ore)

TABLE 4.22: Testwork on Kidd Creek Mines, "D" division ore, showing effect of nitrogen content on pyrite flotation and dissolved oxygen content in the pulp.

test number	nitrogen content in gas (%)	pyrite recovery (%)	dissolved oxygen in pulp (ppm)
12-101	80	7.50	7.8
12-104	90	6.80	5.7
12-103	95	22.14	2.5
12-102	100	35.97	<0.5

The use of gases with 5% oxygen or less promotes the flotation of pyrite. This further confirms the observations made from testwork on the two other ores. Table 5 also shows the effect of varying the oxygen input on the dissolved oxygen content of the pulp. In each test, the dissolved oxygen level adjusted to reach an equilibrium dependent on the oxygen content of the gas bubbled into the cell, which is further illustrated in Figure 4.20.

Table 4.23 shows the effect of varying the nitrogen content on the grade and recovery of sphalerite to the pyrite concentrate. It shows that the zinc recovery to the pyrite concentrate is largely unaffected.

TABLE 4.23: The effect of nitrogen content in the flotation gas, on the grade and recovery of sphalerite to the pyrite concentrate.

test number	nitrogen content in gas (%)	sphalerite grade (%)	sphalerite recovery (%)
12-101	80	12.53	10.38
12-104	90	16.96	14.01
12-103	95	10.70	21.52
12-102	100	4.73	15.24

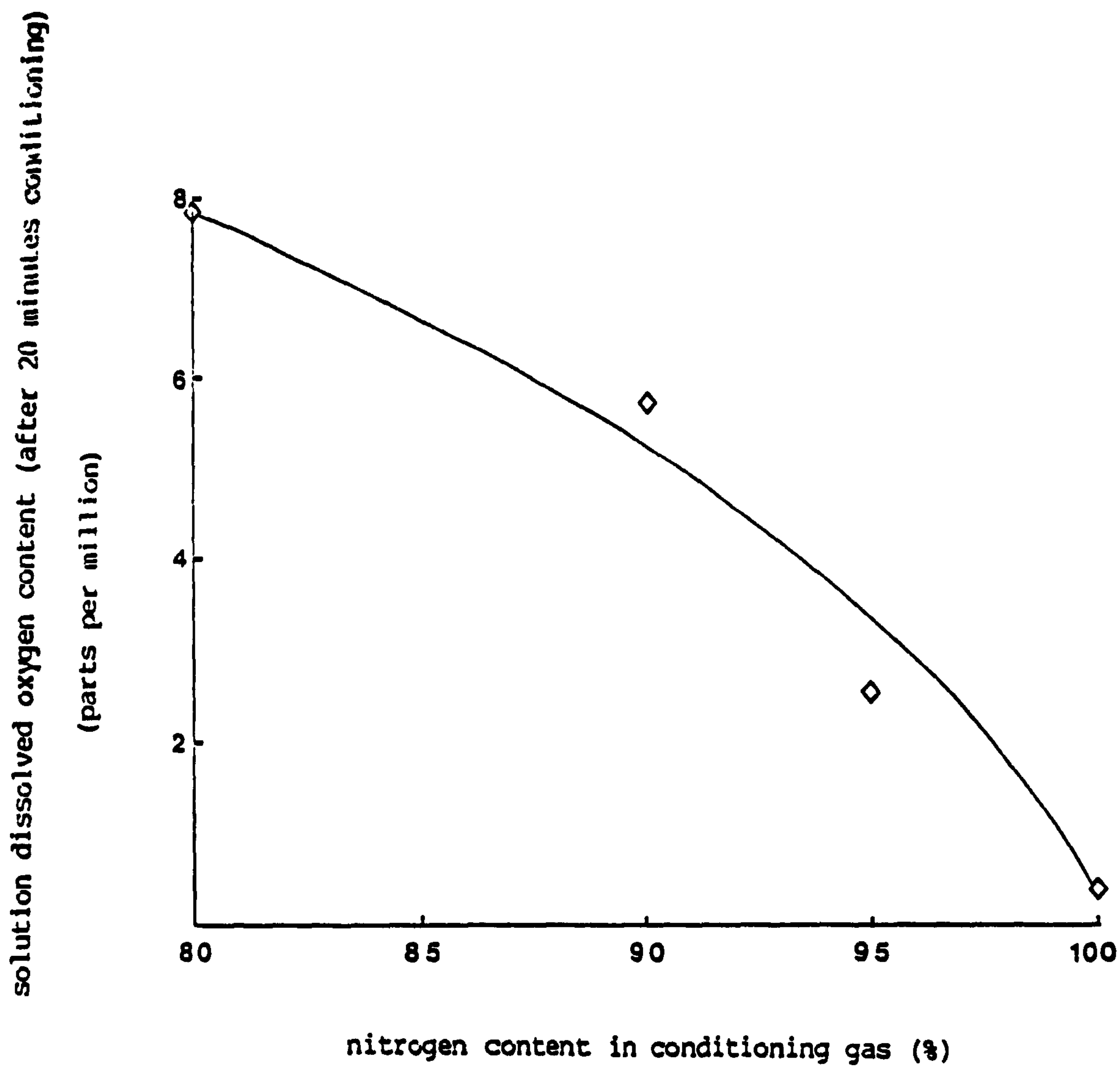


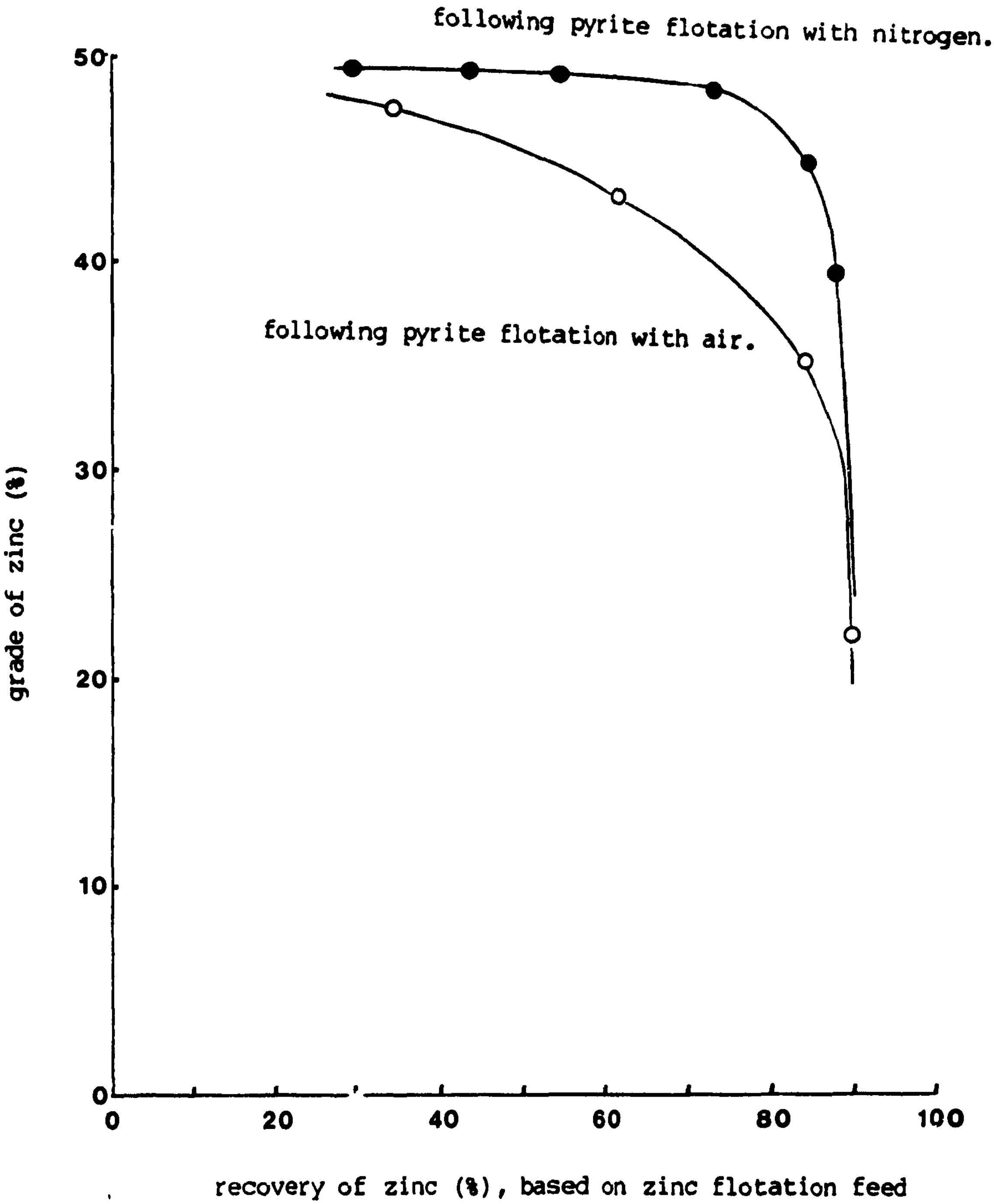
FIGURE 4.20 - Effect of nitrogen enrichment of the conditioning or flotation gas on the dissolved oxygen content of the pulp.

The degree of scatter in zinc recoveries to the bulk and pyrite concentrates makes it difficult to compare zinc flotation grade/recovery relationships based on plant feed. As in previous cases, zinc selectivity is best shown by comparing grades achieved with recoveries based on zinc flotation feed. Figure 4.21 plots the zinc concentrate grades achieved as a function of recovery based on zinc flotation feed. Two tests are highlighted, one incorporating prior pyrite removal through nitrogen flotation and one incorporating prior pyrite removal through air flotation. It shows that removal of pyrite through the use of nitrogen results in an increase in zinc flotation selectivity. The same also applies to impure nitrogen with up to 5% oxygen which is probably as effective as pure nitrogen at floating sufficient pyrite to improve zinc flotation selectivity. The use of 95% nitrogen to float pyrite before zinc flotation, in Test 12-103, led to a zinc concentrate grade of 47% at 83% recovery (based on zinc flotation feed).

4.3.3: The effect of nitrogen conditioning on the dissolved oxygen content of the pulp.

Figure 4.22 shows that nitrogen rapidly purges dissolved oxygen from the pulp. The dissolved oxygen content is reduced to 0.5 ppm in less than one minute.

Not all the oxygen is removed by the nitrogen. Figure 4.22 compares the rate at which dissolved oxygen is purged from (1) water and (2) a pulp containing Kidd Creek ore. Oxygen is removed faster from the pulp than from the water. Conversely, when the



FIGJRE 4.21 - Effect of prior removal of pyrite using nitrogen and air, on the selectivity of zinc rougher flotation of Kidd Creek ore. Graphs show the concentrate grades achieved at respective recoveries based on zinc flotation feed.

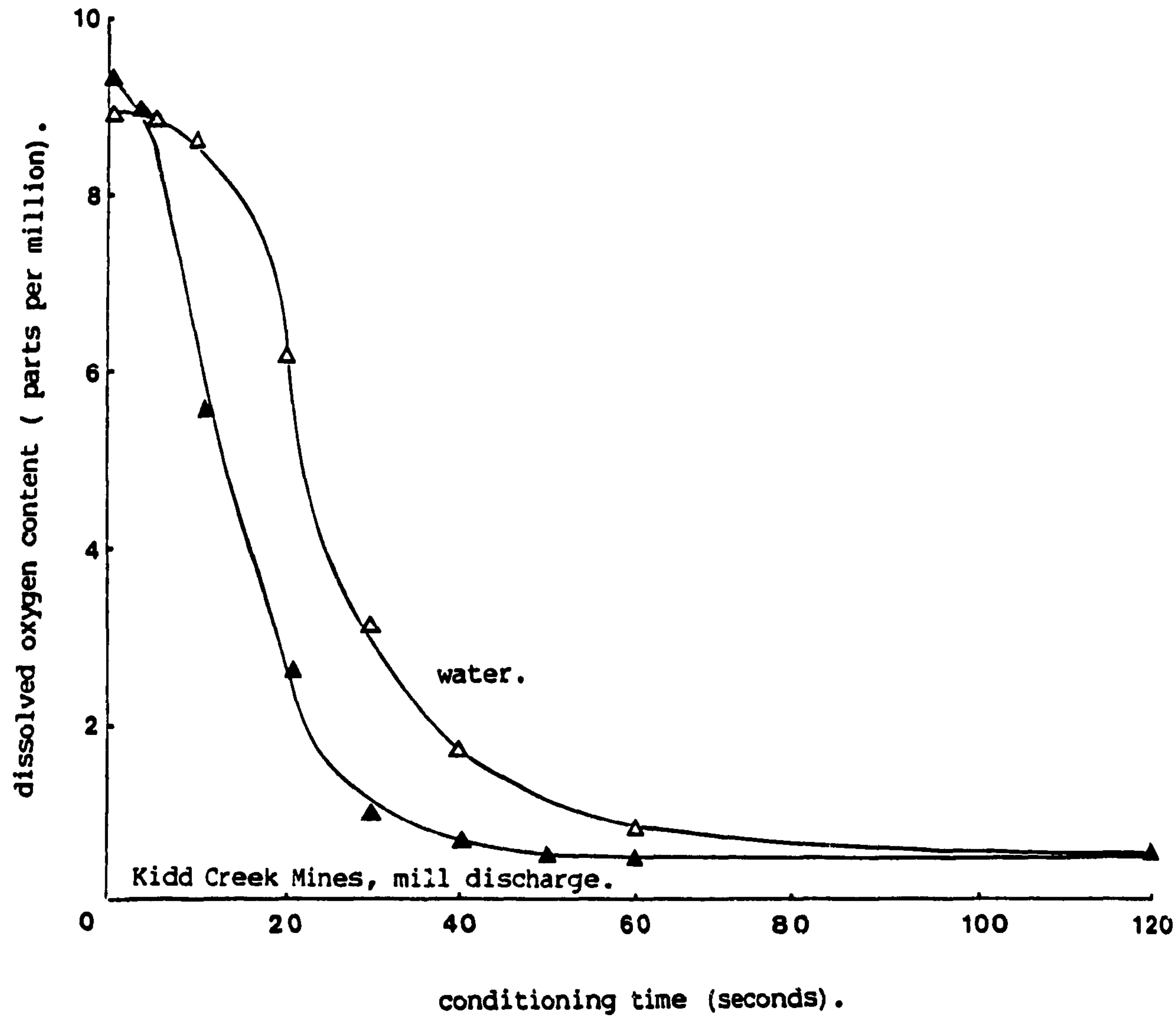


FIGURE 4.22 - Effect of nitrogen conditioning on dissolved oxygen content of water and pulp containing Kidd Creek Mines ore (laboratory mill discharge).

oxygen is re-dissolved through aeration, the dissolved oxygen level rises faster in the water than in the pulp (Figure 4.23).

Both figures suggest that pyrite is constantly drawing oxygen out of solution, accelerating the drop in oxygen content from the pulp during nitrogen conditioning, and retarding the dissolution of oxygen into the pulp water during aeration. Calculations outlined by Appendix 5 suggest that the oxygen demand of the freshly ground ore is roughly 15 ppm dissolved oxygen/minute. This is consistent with other work on similar ores (94).

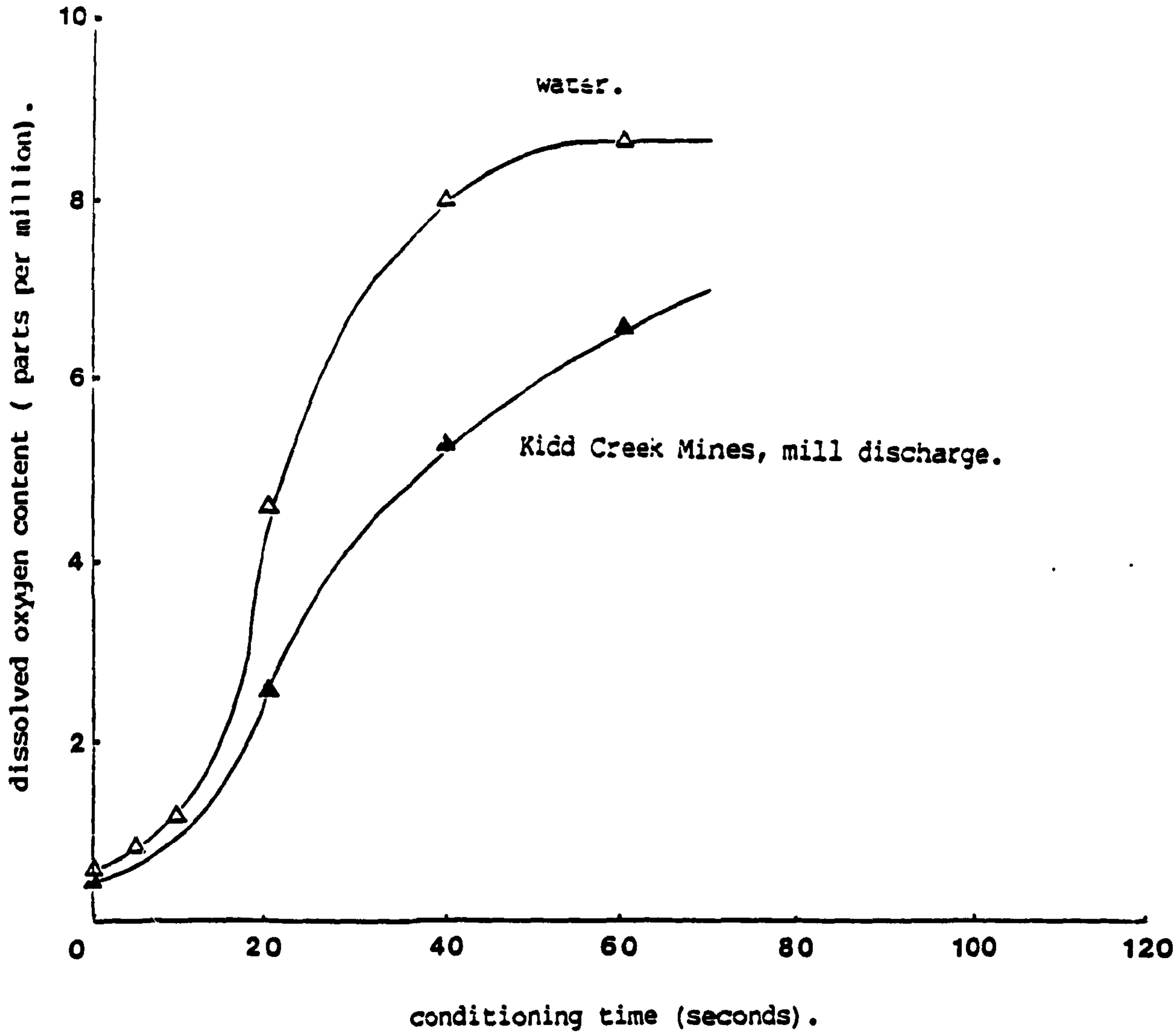


FIGURE 4.23 - Effect of aeration on dissolved oxygen content of water and pulp containing Kidd Creek Mines ore (laboratory mill discharge).

5. DISCUSSION

5.1 COLLECTORLESS FLOTATION

The results described on three Canadian shield ores of apparently similar mineralogy show a wide variation in collectorless flotation response:

* Copper minerals from the Lyon Lake deposit (probably largely chalcopyrite) are highly responsive to collectorless flotation. Both copper concentrate grades and recoveries are superior to those when collector is used. Good recoveries and grades were found under both oxidising and reducing conditions.

* Chalcopyrite from the Mattabi deposit also floated without collector. The recovery was over 80%.

* Little collectorless flotation of chalcopyrite from the Brunswick Mining ore was observed, although sufficient aeration did improve copper recovery from 15% to 40%. This suggests that chalcopyrite may respond to collectorless flotation under sufficiently oxidising conditions.

* Other minerals generally showed poor response to collectorless flotation. Galena can float without collector, but its flotation is slow particularly under reducing conditions (reflecting perhaps that the surface oxidation necessary only occurs slowly.).

This work confirms Finkelstein's observations (22) that the collectorless floatabilities of mineral sulphides vary from ore to ore. Several mechanisms have been proposed to explain collectorless flotation (25,36-7,55,58-9,99,102,107-8). These were described in Section 2.1.1 and are summarised by Figure 5.1.

There are enough mechanisms available to explain the collectorless flotation of minerals, consequently it was considered that a better object of this work would be to propose an application for collectorless flotation rather than to explain it.

Section 2.2 describes the main metallurgical problem facing metallurgists at Mattabi Mines namely copper/lead separation. In all tests so far performed on Mattabi and Lyon Lake ores, strong collectorless flotation of chalcopyrite has been accompanied by slower but significant flotation of galena. A process using collectorless flotation is proposed by Figure 5.2.

While collectorless flotation of chalcopyrite may follow several mechanisms (55,99,107-8), that of galena is likely to be the result of formation of elemental sulphur or some other oxidation product on the mineral surface.(99,102) Figure 4.12 compares the effect of floating galena without collector in reducing conditions (using nitrogen) and oxidising conditions (using air). It confirms that oxidising conditions aid the flotation of galena and so supports the assumption that it must be oxidised to float.

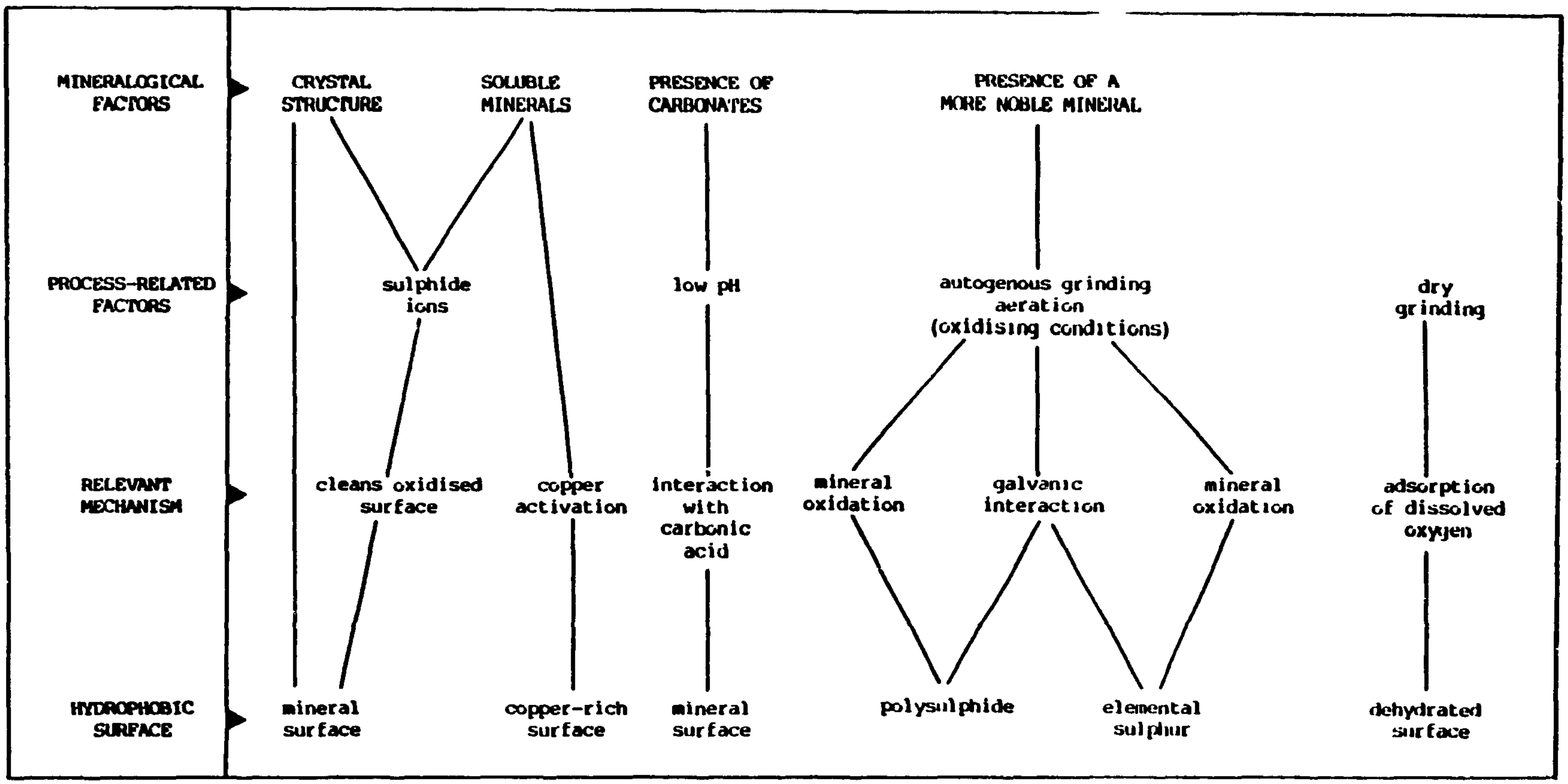


FIGURE 5.1 - Summary of mechanisms behind collectorless flotation as described in Section 2.1.

FIGURE 5.2:Proposed process leading to the production of selective copper and lead concentrates including use of collectorless flotation.

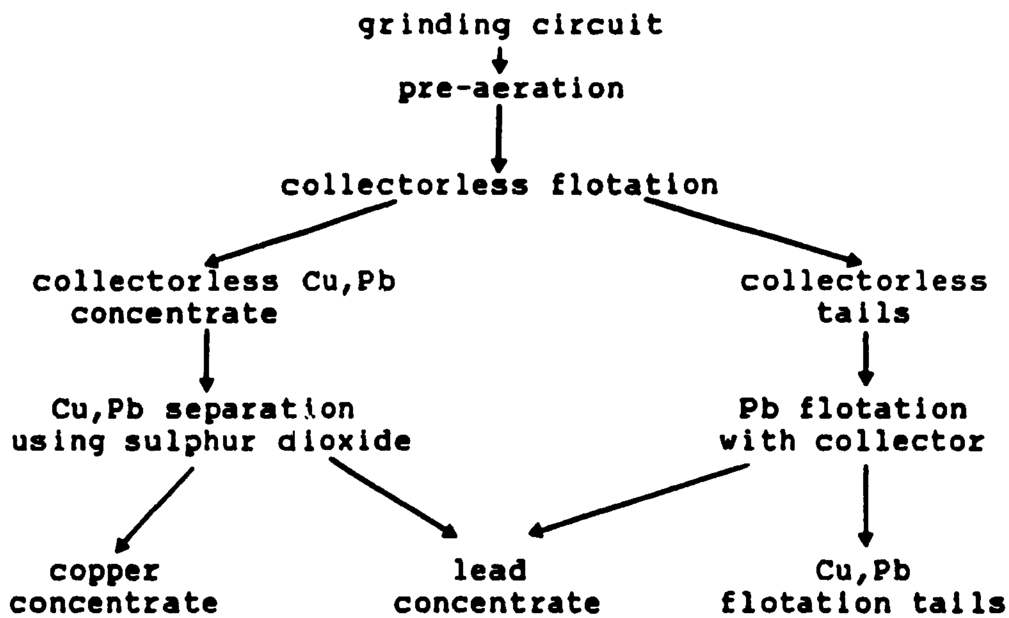


Table 5.1 further shows that oxygen is important, by relating the degree of oxidation of the galena to (1), its collectorless floatability and (2), its susceptibility to sulphite depression:

TABLE 5.1: Effect of degree of oxidation on collectorless flotation and response to sulphite depression.

	degree of oxidation	
	high	low
collectorless floatability	good	poor
response to sulphite depression	good	poor

Thus collectorless flotation is a means by which chalcopyrite and oxidised galena can be separated from clean galena. Table 5.1 also describes that the galena most difficult to depress by sulphite depression is clean galena (91) a fact supported by several aspects of the metallurgy at Mattabi Mines.

* The collectorless flotation of galena is slow, suggesting that galena in the Mattabi ores oxidises only slowly. So much of the galena in the copper/lead separation stage is clean, explaining the poor separability of copper and lead using sulphur dioxide.

* Oxidation of galena would be accelerated by raising the pulp temperature which may help to explain the positive effect of steam.

* Copper/lead separation suffers if the pulp is left to age. Oxygen demand from the pyrite will tend to make conditions more reducing as the pulp ages. This may clean the galena of its oxidation products and reduce copper/lead separability. This was observed during on-site column flotation studies in 1986 (21).

Galena floating with the chalcopyrite in the collectorless concentrate is oxidised and will be effectively depressed using sulphur dioxide. The clean galena left unfloated during collectorless flotation will float well using starvation quantities of collector. Aided by the extra aeration provided by the collectorless float, pyrite will remain depressed with the sphalerite and a high-grade galena concentrate should result, which can be combined with the copper/lead separation tails.

The viability of the process hinges on the consistency of the collectorless flotation of chalcopyrite. It is hoped that regular collectorless flotation tests will be performed on cyclone overflow by personnel at Mattabi Mines to check on the reliability of the mechanism.

As galena flotation to the collectorless concentrate is apparently dependent on oxidising conditions, addition of a reducing agent (such as sodium sulphide) may improve copper collectorless flotation selectivity. Extensive testwork by Yoon and co-workers has shown that sodium sulphide can also promote the collectorless flotation of chalcopyrite (58-9,107-8,99).

5.2 Pyrite flotation using nitrogen

5.2.1 Theoretical aspects.

The initial object of the testwork using nitrogen was to assess whether the use of nitrogen would prevent flotation of pyrite by reducing the pulp potential and the dissolved oxygen content thereby blocking the pyrite-collector interaction.

Comparison of Figures 4.8 (for pyrite flotation in air) and 4.9 (for pyrite flotation in nitrogen) in Section 4.1.8 shows that:

a) Nitrogen does slowly reduce the pulp potential

b) Nitrogen very quickly reduces the dissolved oxygen content, but

c) Nitrogen strongly promotes the flotation of pyrite.

When considering only the collector-mineral interaction, observations (a) and (b) seem to contradict (c). According to the electrochemical theory of mineral-collector interaction, more reducing conditions should tend to send equilibria 5b and hence send 5a to the left (24,60-1) This infers that the mineral-collector reaction would be retarded.

$$MS + X^- = MS(X) + e^- \quad .....(5a)$$

$$H_2O + 1/2.O_2 + 2.e^- = 2.(OH^-) \quad ....(5b)$$

Without analysing the mineral surface it is not possible to confirm this.

So another mechanism is altering the hydrophobicity of the mineral surface. With only a fraction of the surface covered by a collector, the hydrophobicity of a mineral surface is likely to be a balance between the amount of collector adsorbed and the hydrophobicity of the mineral surface without adsorbed collector. This balance is particularly applicable to pyrite. Gaudin (28) suggested that a pyrite surface is constantly changing, through formation of hydrophilic oxides of sulphur and possibly iron. Fuerstenau attributed the depression of pyrite with permanganate to the adsorption of hydroxyl ions onto the pyrite surface through reaction with ferric ions in the mineral. (23). Hoyack and Raghavan(43) proposed a similar mechanism for the depression of pyrite using sulphite ions.

The possible role of galvanic interactions altering the mineral surface has been proposed by a number of investigators (40,44,49,79). Galvanic interactions have been used to explain effects of grinding media (1,14,44,51,79,97) on flotation performance. Similar galvanic effects are likely to occur between pyrite, the most noble mineral, and other base metal sulphides (49,60,75-9). A model of such a mechanism is illustrated by Figure 2.3. Pyrite, being more noble, will tend to draw electrons from sphalerite. This will oxidise sphalerite and promote formation of iron hydroxides on the pyrite surface through reduction of dissolved oxygen. Majima (60) notes that such a galvanic interaction has been found to increase the rate of oxidation of a sulphide mineral through association with pyrite by eight to twenty times. This leads to the formation of hydrophobic, elemental sulphur on the mineral surface.

Such oxidation will aid sphalerite flotation and hydrophilic iron hydroxides on the pyrite surface will depress pyrite. So the effect would be to improve selective flotation of sphalerite from pyrite.

By stopping the supply of oxygen, nitrogen flotation blocks the mechanism. Iron hydroxides will no longer form on the pyrite surface. The increased hydrophobicity of the pyrite will then allow flotation of pyrite with only minimal dosages of collector.

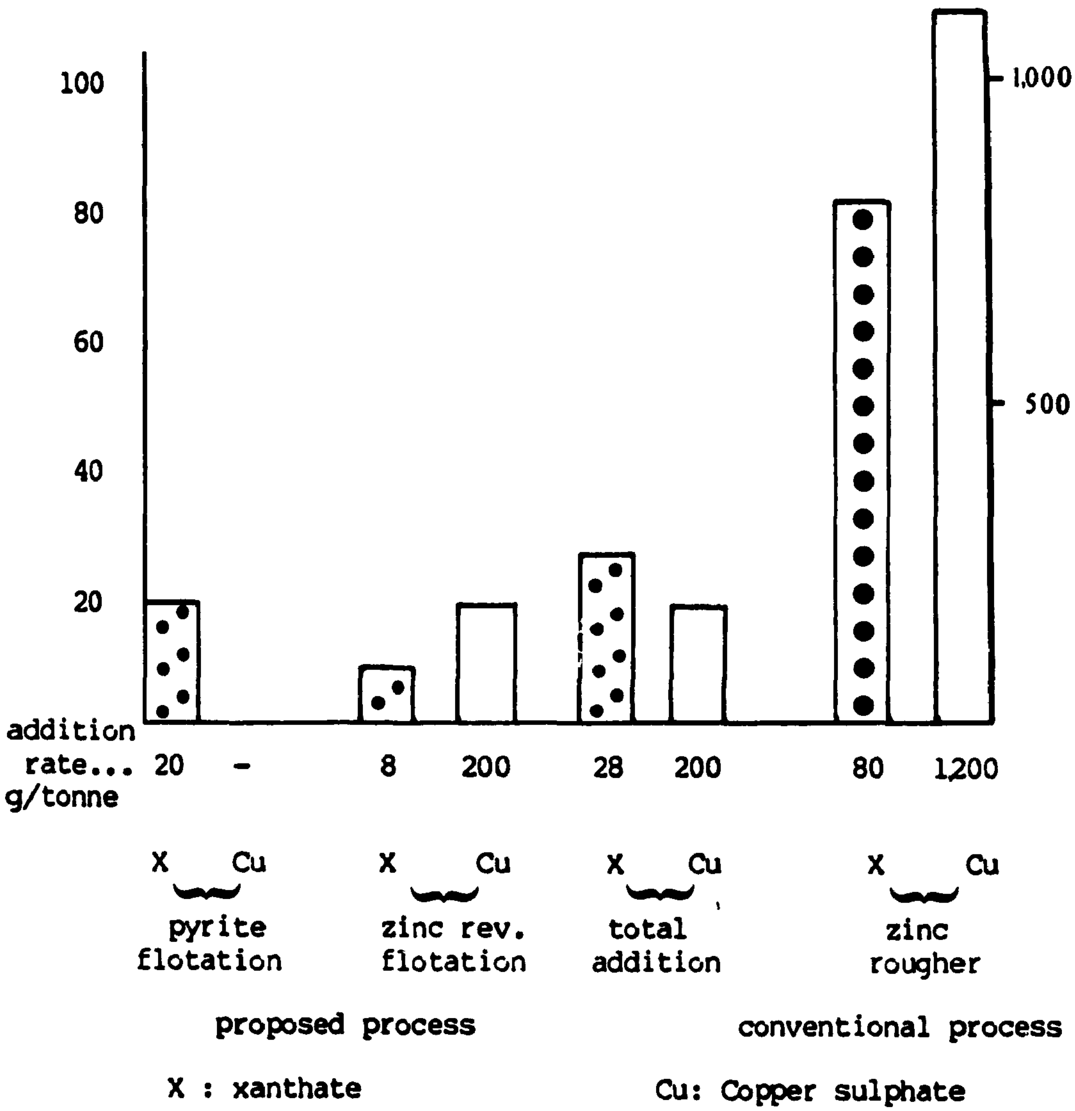


FIGURE 5.3 - Exposure of pyrite to collector and copper sulphate activator, in the conventional and proposed processes.

5.2.2 Operational Aspects.

The results section showed that a relatively high grade pyrite concentrate could be floated from the bulk flotation tails. It also showed that entrained zinc could be selectively recovered from the pyrite concentrate by reverse flotation with collector following copper activation, in air and at pH 10-11 (although other pH levels were not tested). An overall metallurgical balance for the proposed process is illustrated by Figure 4.7.

It shows that the proposed process produced a zinc rougher concentrate grade 50% higher than that produced by the conventional route, at a similar recovery. While this is unlikely to improve the overall grade/recovery relationship of a circuit it may make the cleaner circuit simpler and easier to operate.

Inspection of Figure 5.3 reveals that the proposed process largely avoids the contact of pyrite with copper sulphate. While the potential for copper sulphate activation of pyrite is not well recognised in North America, Yamomoto (106) notes this use and copper sulphate is used to activate pyrite in flotation circuits in South Africa (67). Pyrite would also be less exposed to collector. This would suggest several advantages:

* Easier overall pyrite rejection (indicated by the improved zinc rougher grades).
* Less reliance on pH for pyrite rejection (with the resultant saving in lime costs).

* Reduced consumption of copper sulphate and xanthate by eliminating their wasteful adsorption onto the pyrite surface.

The nature of the zinc reverse flotation concentrate suggests that it may isolate locked particles. This would make it a particularly good stream to regrind.

The main problem associated with the use of the proposed flowsheet is the supply of nitrogen. Based on laboratory tests, 400 tonnes of fresh nitrogen gas will be needed per day for a plant the size of Brunswick Mining (treating 10,250 tonnes per day). For both economic and environmental reasons, some form of recirculation system will be needed (i.e. closed cells). In this case air could be used as the carrier gas, oxygen being quickly consumed by the pyrite. Some nitrogen supply may be necessary to ensure a positive pressure in the flotation cell, stopping air from leaking into the system, but this is unlikely to be more than 20 tonnes per day. Conditioning could be performed in a closed tank. Conditioning gas may not be necessary. If it is then the gas can be recirculated in an enclosed system. The supply of extra nitrogen could be manipulated automatically by dissolved oxygen levels at the end of pyrite flotation. Tests so far suggest that the dissolved oxygen level should be below 2 ppm.

Another aspect of the effect of nitrogen, or oxygen deficient gases on the flotation of pyrite concerns the use of flotation columns. Calculations outlined in Appendix 5 suggest that the amount of air injected into a column is not enough to satisfy the demand for oxygen from a pyritic ore. Therefore, as air rises through the cell it becomes deficient in oxygen and will tend to increase the floatability of pyrite. So, while this needs to be checked it suggests that the geometry of the cell could affect the chemical environment of the pulp, the flotation chemistry and the grade/recovery relationship of a flotation process. This may limit the use of columns in processing streams which have a high oxygen demand.

5.2.3 Economics of the process (Balance based on Brunswick Mining)

As mentioned in the previous section, use of fresh nitrogen cannot be economically justified. The capital cost of the plant would be in the region of $8 million and the running costs $16,000 per day.

So the balance developed in this section is based on 20 tonnes of nitrogen a day, enclosing the flotation cells and circulating the gas. At Brunswick Mining the cells (Outokumpu) are virtually enclosed already and it is assumed the gas recirculation system can be home-built at negligible cost.

The cost of a nitrogen plant to produce 20 tonnes of nitrogen a day is approximately $750,000. Its running costs are $800 per day. Based on straight-line depreciation and not including tax considerations, the capital cost over a 15 year period is equivalent to 1.3 cents per tonne of ore. Running costs are equivalent to 7.6 cents per tonne of ore. The total cost of the nitrogen is therefore 8.9 cents per tonne.

Figure 5.4 compares approximate reagent costs in a zinc circuit with the cost of nitrogen. It shows that the cost of 20 tonnes/day nitrogen can be justified by a 12% saving in lime or 19% saving in copper sulphate consumption. The cost of nitrogen is unlikely to be justified by savings in collector (requiring a 57% saving).

Operating costs (power, maintenance etc.) of the zinc flotation circuit are normally about 60 cents per tonne of ore (2,42). The use of nitrogen can then be justified by a 15% reduction in overall zinc flotation capacity.

At this stage, it is not possible to predict that nitrogen flotation is economical. The cost comparisons listed above do, however, show that the process is relatively cheap in comparison to other flotation costs. This suggests that any improvement in zinc/pyrite separation efficiency which results in the use of lower pH and less reagents will probably justify the extra costs of the process. The process could be particularly attractive to more isolated operations where transportation of lime and copper sulphate becomes very costly (88).

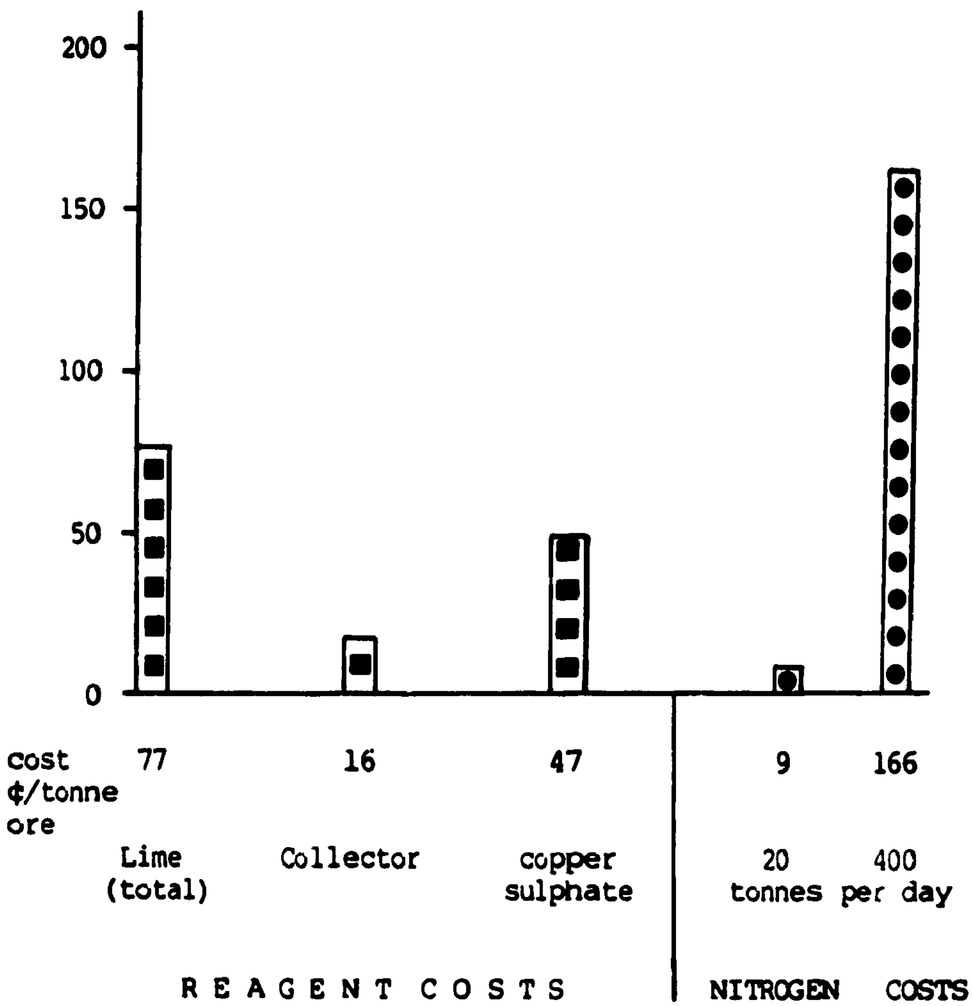


FIGURE 5.4 - Comparison of approximate plant reagent costs with expected costs of using nitrogen (based on 400 and 20 tonnes per day).

6. CONCLUSIONS

6.1 COLLECTORLESS FLOTATION

* The collectorless floatability of chalcopyrite varied from ore to ore, though all ores tested showed some response to collectorless flotation. The collectorless recoveries of chalcopyrite in ores from Mattabi are similar to those using collector.

* Some collectorless flotation of galena was observed from ores from Mattabi Mines, particularly under oxidising conditions.

* A process is proposed whereby chalcopyrite and oxidised galena are floated without collector. These are subsequently separated by sulphur dioxide depression of galena. The remaining untarnished galena is floated with collector.

* Pyrite and sphalerite showed no response to collectorless flotation in all ores tested.

6.2 NITROGEN FLOTATION.

* The use of nitrogen strongly promotes the flotation of pyrite. Pyrite flotation is selective from zinc-bearing minerals but not from copper- and lead-bearing minerals.

* Nitrogen conditioning and flotation reduces the pulp potential. The level of dissolved oxygen in solution drops to below 0.5 ppm. within 1 minute, through the use of nitrogen.

* Pyrite flotation is probably linked to the removal of dissolved oxygen. This blocks a galvanic interaction between pyrite and sphalerite, which otherwise serves to depress the pyrite through OH- formation.

* Nitrogen flotation can be used to float pyrite after bulk copper,lead flotation and before zinc flotation. This improves the rougher concentrate grade achieved by subsequent zinc flotation.

* Aerating the pyrite concentrate pulp depresses the pyrite Copper activation and reverse zinc flotation with collector in air selectively recovers zinc minerals from the pyrite concentrate.

* The proposed process incorporating nitrogen flotation and reverse flotation of zinc-bearing minerals reduces the exposure of pyrite to collectors and copper sulphate. This may explain the improved zinc rougher grades achieved. The

process may also isolate locked zinc-pyrite particles in the reverse concentrate, in which case regrinding could liberate extra zinc minerals.

* The process is probably viable economically at 20 tonnes nitrogen per day if savings in lime of 17% are realised.

7. RECOMMENDED FURTHER WORK

7.1 COLLECTORLESS FLOTATION

7.1.1 To assess the potential of the proposed process:

- Regular on-site collectorless flotation tests should be performed to check the reliability of collectorless flotation.

- Copper,lead separation of the collectorless flotation concentrate should be investigated. Galena should be depressed using sulphur dioxide.

7.1.2 To improve on the process:

- As collectorless flotation of galena seems to be based on surface oxidation, collectorless flotation with a reducing agent (e.g. sodium sulphite) may result in a selective copper concentrate.

- Alternatively, flotation recovery of galena could be maximised. While galena floats slowly without collector, it may be selectively recovered from pyrite and sphalerite if allowed to float to the limit of recovery.

7.2 NITROGEN FLOTATION

7.2.1 To increase understanding of nitrogen flotation.

- Nitrogen testwork should be performed on Mattagami ore, which contains mainly pyrrhotite. Pyrrhotite is less noble than pyrite but has a higher oxygen demand.

- A flotation column should be used to check in whether the mis-direction of zinc is the result of entrainment.

7.2.2 To assess commercial potential of nitrogen flotation.

- One of the potential rewards of removing pyrite before zinc flotation is a saving in lime costs. To check this,flotation of a zinc concentrate after pyrite flotation under less alkaline conditions should be tested.

- Continuous tests should be performed to optimise pyrite flotation.

- The process is only likely to be viable if oxygen deficient gas is produced by enclosing the cells and recirculating the gas. The production of sufficient 'fresh' nitrogen is likely to be too expensive. Tests should be run using an enclosed cell to establish whether pyrite can be promoted in this way.

- Mineralogical analysis of the reverse zinc concentrate should be undertaken to identify the concentration of locked particles in the sample.

- Nitrogen should be tested on the pyrite reverse flotation stage which is currently in some zinc circuits.(e.g Kidd Creek Mines).

- Most ways of producing nitrogen also produce oxygen. As a logical extension of nitrogen flotation to float pyrite and aeration to depress pyrite, oxygen-enriched aeration could improve pyrite rejection in the copper,lead bulk float. The use of oxygen enriched gases during pre-aeration and bulk flotation should be tested.

7.2.3 Other related testwork.

- Tests should be run which check the dissolved oxygen content and perhaps pulp potential of the pulp at different levels in a flotation column, treating an ore with a high oxygen demand.

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9: APPENDIX 1

GRINDING TEST DATA

Brunswick Mining grind time (minutes)	wet sieve analysis percent passing 74μm	37μm
20	83	44
30	95	67
40	100	92

Mattabi Mines grind time (minutes)	wet sieve analysis percent passing 300μm	150μm	74μm
30	100	100	95
20	100	99	77
10	98	86	48

Kidd Creek Mines grind time (minutes)	wet sieve analysis percent passing 74μm	45μm
20	73	20
30	76	64
40	79	71

10. APPENDIX 2 - BRUNSWICK MINING ORE TESTWORK

COLLECTORLESS FLOTATION

10-101 Collectorless flotation in air, followed by bulk copper, lead flotation and zinc flotation.

10-102 Collectorless flotation in nitrogen, followea by bulk copper, lead flotation and zinc flotation in nitrogen.

10-103 Collectorless flotation then zinc flotation in nitrogen.

10-104 Collectorless flotation then zinc flotation in air.

NITROGEN FLOTATION

10-201 Bulk copper, lead flotation in air, pyrite flotation in air and nitrogen, and zinc flotation in air.

10-202 Bulk flotation in air, pyrite flotation in air and zinc flotation in air.

10-203 Bulk copper, lead flotation in air, pyrite flotation in air then nitrogen and zinc flotation in air.

10-204 Bulk copper, lead flotation in air, pyrite flotation in nitrogen and zinc flotation in air.

10-205 Bulk copper, lead, pyrite flotation in nitrogen with stage addition of collector, then zinc flotation in nitrogen.

10-206 Bulk copper, lead, pyrite flotation in nitrogen, single addition of collector, zinc flotation in nitrogen.

10-207 Copper activation then zinc flotation in nitrogen only.

10-208 Bulk copper, lead, pyrite flotation in nitrogen, zinc flotation in nitrogen.

10-209 Nitrogen conditioning, then copper, lead, pyrite flotation in air and zinc flotation in air.

10-210 Nitrogen conditioning, then copper, lead, pyrite flotation in air, folowed by zinc flotation in air.

10-211 Bulk copper,lead, pyrite flotation in nitrogen then zinc flotation in air.

10-212 Bulk copper, lead flotation in air, then pyrite flotation in nitrogen with zinc reverse cleaning, finally zinc flotation in air.

10-213 Bulk copper, lead flotation in air, then pyrite flotation in nitrogen with zinc reverse flotation, finally zinc flotation of pyrite tails in air. (repeat of test 10-212)

10-214 Bulk copper, lead flotation in air, pyrite flotation in nitrogen, zinc flotation in air.

10-215 Bulk copper, lead flotation in air, pyrite flotation and zinc flotation in air.

STANDARD FLOTATION

10-301 Standard copper, lead flotation and zinc flotation in air.

FLOTATION TESTS ON-SITE AT BRUNSWICK MINING.

10-401 Bulk copper, lead flotation in air, pyrite flotation in air and zinc flotation.

10-402 Bulk copper, lead flotation in air, pyrite flotation in nitrogen and zinc flotation in air.

10-403 Bulk copper, lead flotation in air, pyrite flotation in nitrogen with zinc reverse cleaning and zinc flotation of pyrite tails in air.

10-404 Bulk copper, lead flotation in air, pyrite flotation in nitrogen and zinc flotation in air. (McGill Std procedure).

ARGON FLOTATION

10-501 Bulk copper, lead flotation in air, pyrite flotation in argon and zinc flotation in air.

sample reference	SOLIDS MASS BALANCE: sample weight	mass pull sample	mass pull total	COPPER MASS BALANCE: copper assay (%)	copper units	copper recovery stage	copper recovery total	LEAD MASS BALANCE: lead assay (%)	lead units	lead recovery stage	lead recovery total	ZINC MASS BALANCE: zinc assay (%)	zinc units	zinc recovery stage	zinc recovery total	IRON MASS BALANCE: iron assay (%)	iron units	iron recovery stage	iron recovery total
collectorless rougher - 2 minutes A	40.45	4.41%	4.41%	0.38	0.017	4.99%	4.99%	5.28	0.233	7.09%	7.09%	8.01	0.354	4.10%	4.10%	27.70	1.223	4.96%	4.96%
collectorless rougher - 2 minutes B	17.28	1.89%	6.30%	0.38	0.007	2.13%	7.12%	4.80	0.091	2.75%	9.84%	9.07	0.171	1.99%	6.09%	26.70	0.503	2.04%	7.00%
collectorless rougher - 2 minutes C	12.99	1.42%	7.72%	0.36	0.005	1.52%	8.64%	4.62	0.065	1.99%	11.83%	9.24	0.131	1.52%	7.61%	25.80	0.366	1.49%	8.48%
collectorless rougher - 2 minutes D	9.69	1.06%	8.77%	0.36	0.004	1.13%	9.77%	4.36	0.046	1.40%	13.23%	9.01	0.095	1.11%	8.72%	24.60	0.260	1.05%	9.54%
collectorless rougher - 2 minutes E	6.83	0.75%	9.52%	0.37	0.003	0.82%	10.59%	4.42	0.033	1.00%	14.23%	9.32	0.069	0.81%	9.52%	24.80	0.185	0.75%	10.29%
collectorless rougher - 2 minutes F	6.67	0.73%	10.25%	0.37	0.003	0.80%	11.39%	4.30	0.031	0.95%	15.18%	9.12	0.066	0.77%	10.29%	24.30	0.177	0.72%	11.00%
collectorless rougher - 2 minutes G	4.05	0.44%	10.69%	0.37	0.002	0.49%	11.88%	4.40	0.019	0.59%	15.77%	9.52	0.042	0.49%	10.78%	24.90	0.110	0.45%	11.45%
pyrite rougher - 2 minutes A	132.02	14.41%	25.09%	0.47	0.068	20.14%	32.02%	6.44	0.928	28.21%	43.98%	2.11	0.304	3.53%	14.31%	38.40	5.532	22.43%	33.88%
pyrite rougher - 2 minutes B	86.52	9.44%	34.54%	0.45	0.042	12.64%	44.65%	4.30	0.406	12.34%	56.32%	2.60	0.245	2.85%	17.16%	39.40	3.729	15.08%	48.97%
pyrite rougher - 2 minutes C	54.88	5.99%	40.52%	0.51	0.031	9.08%	53.74%	3.84	0.230	6.99%	63.31%	3.02	0.181	2.10%	19.26%	39.60	2.371	9.62%	58.59%
pyrite rougher - 2 minutes D	55.08	6.01%	46.53%	0.50	0.030	8.94%	62.68%	3.28	0.197	5.99%	69.31%	3.15	0.189	2.20%	21.46%	39.80	2.392	9.70%	68.28%
zinc rougher - time 30 seconds	84.90	9.26%	55.80%	0.48	0.044	13.23%	75.90%	4.72	0.437	13.29%	82.60%	18.30	1.695	19.68%	41.14%	28.10	2.603	10.56%	78.84%
zinc rougher - time 30 seconds	46.43	5.07%	60.86%	0.39	0.020	5.88%	81.78%	2.50	0.127	3.85%	86.45%	25.40	1.287	14.94%	56.09%	21.40	1.084	4.40%	83.23%
zinc rougher - time 1 minute	20.59	2.25%	63.11%	0.37	0.008	2.47%	84.25%	2.06	0.046	1.41%	87.86%	30.40	0.683	7.93%	64.02%	19.30	0.434	1.76%	84.99%
zinc scavenger - time 30 seconds	49.08	5.36%	68.47%	0.36	0.019	5.73%	89.99%	3.08	0.165	5.01%	92.87%	33.00	1.767	20.52%	84.54%	18.40	0.985	4.00%	88.99%
zinc scavenger - time 1 minute	31.32	3.42%	71.88%	0.34	0.012	3.46%	93.44%	2.04	0.070	2.12%	94.99%	24.90	0.851	9.88%	94.42%	18.50	0.632	2.56%	91.55%
zinc scavenger - time 2 minutes	8.65	0.94%	72.83%	0.32	0.003	0.90%	94.34%	1.90	0.018	0.55%	95.54%	16.40	0.155	1.80%	96.21%	19.20	0.181	0.73%	92.29%
final tails	249.03	27.17%	100.00%	0.07	0.019	5.66%	100.00%	0.54	0.147	4.46%	100.00%	1.20	0.326	3.79%	100.00%	7.00	1.902	7.71%	100.00%
reconstituted feed	916.46				0.336	100.00%			3.289	100.00%			8.612	100.00%			24.660	100.00%	

TEST SUMMARY:	sample weight	mass pull sample	mass pull total	copper assay %	recovery stage	recovery total	lead assay %	recovery stage	recovery total	zinc assay %	recovery stage	recovery total	iron assay %	recovery stage	recovery total
bulk flotation	93.91	10.69%	10.69%	0.37	11.88%	11.88%	4.85	15.77%	15.77%	8.69	10.78%	10.78%	26.42	11.45%	11.45%
pyrite final concentrate	328.50	35.84%	46.53%	0.48	50.80%	62.68%	4.91	53.53%	69.31%	2.57	10.68%	21.46%	39.10	56.83%	68.29%
zinc rougher flotation	240.97	26.29%	72.83%	0.40	31.67%	94.34%	3.21	26.23%	95.54%	23.90	74.75%	96.21%	21.83	24.01%	92.29%
final flotation tails	249.03	27.17%	100.00%	0.07	5.66%	100.00%	0.54	4.46%	100.00%	1.20	3.79%	100.00%	7.00	7.71%	100.00%

10-101 Collectorless flotation in air, followed by bulk copper,lead flotation and zinc flotation.

FLOTATION CONDITIONS

	pH	activator added g/t	Pre-conditioning gas	Pre-conditioning time	collector type	collector addition g/t	flotation gas
collectorless rougher - 2 minutes A	8.5	-	nitrogen	25 min	-	-	nitrogen
collectorless rougher - 2 minutes B	8.5	-	-	-	-	-	nitrogen
collectorless rougher - 2 minutes C	8.5	-	-	-	-	-	nitrogen
collectorless rougher - 2 minutes D	8.5	-	-	-	-	-	nitrogen
collectorless rougher - 2 minutes E	8.5	-	-	-	-	-	nitrogen
collectorless rougher - 2 minutes F	8.5	-	-	-	-	-	nitrogen
collectorless rougher - 2 minutes G	8.5	-	-	-	-	-	nitrogen
pyrite rougher - 2 minutes A	8.5	-	-	-	SIPX	50	nitrogen
pyrite rougher - 2 minutes B	8.5	-	-	-	-	-	nitrogen
pyrite rougher - 2 minutes C	8.5	-	-	-	-	-	nitrogen
pyrite rougher - 2 minutes D	8.5	-	-	-	-	-	nitrogen
zinc rougher - 30 seconds	10.0	1200	none	5 min	SIPX	50	nitrogen
zinc rougher - 1 minute	10.0	-	-	-	-	-	nitrogen
zinc rougher - 2 minutes	10.0	-	-	-	-	-	nitrogen
zinc scavenger - 30 seconds	10.0	-	-	-	SIPX	30	nitrogen
zinc scavenger - 1 minute	10.0	-	-	-	-	-	nitrogen
zinc scavenger - 2 minutes	10.0	-	-	-	-	-	nitrogen

GRINDING CONDITIONS:

30 minutes, mild steel charge

1200 g/t zinc sulphate

10-101 Collectorless flotation in air, followed by bulk copper,lead flotation and zinc flotation.

	SOLIDS MASS BALANCE			COPPER MASS BALANCE				LEAD MASS BALANCE				ZINC MASS BALANCE				IRON MASS BALANCE				
	sample weight	mass pull		copper		copper recovery		lead		lead recovery		zinc		zinc recovery		iron		iron recovery		
sample reference	(grams)	sample	total	assay (%)	units	stage	total	assay (%)	units	stage	total	assay (%)	units	stage	total	assay (%)	units	stage	total	
collectorless rougher - 2 minutes A	44.35	4.35%	4.35%	1.06	0.046	14.33%	14.33%	6.40	0.270	8.90%	8.90%	6.87	0.299	3.58%	3.58%	29.30	1.274	5.20%	5.20%	
collectorless rougher - 2 minutes B	27.37	2.68%	7.03%	0.96	0.026	8.01%	22.34%	5.00	0.134	4.29%	13.19%	8.01	0.215	2.58%	6.16%	27.70	0.743	3.03%	8.23%	
collectorless rougher - 2 minutes C	10.91	1.07%	8.10%	1.04	0.011	3.46%	25.80%	5.04	0.054	1.72%	14.91%	8.14	0.087	1.04%	7.21%	27.70	0.296	1.21%	9.44%	
collectorless rougher - 2 minutes D	8.71	0.85%	8.95%	1.35	0.012	3.58%	29.38%	5.22	0.045	1.43%	16.34%	8.79	0.075	0.90%	8.11%	28.20	0.241	0.98%	10.43%	
collectorless rougher - 2 minutes E	12.48	1.22%	10.18%	1.19	0.015	4.53%	33.91%	5.28	0.065	2.07%	18.40%	8.51	0.104	1.25%	9.36%	26.00	0.318	1.30%	11.73%	
collectorless rougher - 2 minutes F	8.99	0.88%	11.06%	1.05	0.009	2.88%	36.79%	5.62	0.050	1.58%	19.99%	8.65	0.076	0.91%	10.27%	26.50	0.233	0.95%	12.68%	
pyrite rougher 2 minutes A	157.01	15.39%	26.44%	0.79	0.122	37.81%	74.60%	10.80	1.662	53.16%	73.15%	9.21	1.417	17.01%	27.28%	30.60	4.709	19.23%	31.91%	
pyrite rougher 2 minutes B	25.60	2.51%	28.95%	0.48	0.012	3.75%	78.35%	6.90	0.173	5.54%	78.68%	11.90	0.299	3.58%	30.86%	29.40	0.738	3.01%	34.92%	
pyrite rougher - 2 minutes C	15.60	1.53%	30.48%	0.31	0.005	1.47%	79.82%	3.78	0.058	1.85%	80.53%	12.70	0.194	2.33%	33.19%	28.70	0.429	1.79%	36.71%	
pyrite rougher 2 minutes D	6.03	0.59%	31.07%	0.31	0.002	0.57%	80.39%	3.30	0.020	0.62%	81.15%	13.20	0.078	0.94%	34.13%	28.50	0.168	0.69%	37.40%	
zinc rougher - time 30 seconds	51.87	5.08%	36.16%	0.18	0.009	2.85%	83.24%	1.22	0.062	1.98%	83.14%	37.00	1.881	22.57%	56.70%	13.40	0.681	2.78%	40.18%	
zinc rougher - time 1 minute	32.93	3.23%	39.38%	0.17	0.005	1.71%	84.94%	1.20	0.039	1.24%	84.38%	34.90	1.126	13.52%	70.22%	17.20	0.555	2.27%	42.05%	
zinc rougher - time 2 minutes	40.36	3.96%	43.34%	0.17	0.007	2 09%	87.04%	1.28	0.051	1.62%	86.00%	31.50	1.246	14.95%	85.18%	18.60	0.736	3.00%	45.45%	
zinc scavenger - time 30 seconds	35.82	3.51%	46.85%	0.18	0.006	1.97%	89.00%	1.54	0.054	1.73%	87.73%	20.80	0.730	8.76%	93.94%	27.30	0.958	3.91%	49.36%	
zinc scavenger - time 1 minute	21.67	2.12%	48.97%	0.16	0.003	1.06%	90.06%	1.62	0.034	1.10%	88.83%	8.42	0.179	2.15%	96.08%	30.80	0.654	2.67%	52.03%	
zinc scavenger - time 2 minutes	11.43	1 12%	50.09%	0.18	0.002	0.63%	90.69%	1.78	0.020	0.64%	89.46%	5.51	0.062	0.74%	96.83%	32.90	0.369	1.50%	53.54%	
final tails	509.20	49.91%	100.00%	0.06	0 030	9.31%	100.00%	0.66	0.329	10.54%	100.00%	0.53	0.264	3.17%	100.00%	22.80	11.370	46.46%	100.00%	
reconstituted feed	1020.33				0.321	100.00%			3.126	100.00%			8.332	100.00%			24.490	100.00%		

TEST SUMMARY:	sample weight	mass pull sample	mass pull total	copper assay %	recovery stage	recovery total	lead assay %	recovery stage	recovery total	zinc assay %	recovery stage	recovery total	iron assay %	recovery stage	recovery total
bulk flotation	112.81	11.06%	11.06%	1.07	36.79%	36.79%	5.65	19.99%	19.99%	7.74	10.27%	10.27%	28.08	12.68%	12.68%
pyrite final concentrate	204.24	20.02%	31.07%	0.70	43.60%	80.39%	9.55	61.17%	81.15%	9.93	23.86%	34.13%	30.24	24.72%	37.40%
zinc rougher flotation	194.08	19.02%	50.09%	0.17	10.29%	90.69%	1.37	8.31%	89.46%	27.46	62.70%	96.83%	20.78	16.14%	53.54%
final flotation tails	509.20	49.91%	100.00%	0.06	9.31%	100.00%	0.66	10.54%	100.00%	0.53	3.17%	100.00%	22.80	46.46%	100.00%

10-102 Collectorless flotation in nitrogen, followed by bulk copper,lead flotation and zinc flotation in nitrogen

FLOTATION CONDITIONS

sample reference	pH	activator added g/t	Pre-conditioning gas	Pre-conditioning time	collector type	collector addition g/t	flotation gas
collectorless rougher - 2 minutes A	8.5	-	air	25 min	-	-	air
collectorless rougher - 2 minutes B	8.5	-	-	-	-	-	air
collectorless rougher - 2 minutes C	8.5	-	-	-	-	-	air
collectorless rougher - 2 minutes D	8.5	-	-	-	-	-	air
collectorless rougher - 2 minutes E	8.5	-	-	-	-	-	air
collectorless rougher - 2 minutes F	8.5	-	-	-	-	-	air
pyrite rougher - 2 minutes A	8.5	-	-	-	SIPX	50	air
pyrite rougher - 2 minutes B	8.5	-	-	-	-	-	air
pyrite rougher - 2 minutes C	8.5	-	-	-	-	-	air
pyrite rougher - 2 minutes D	8.5	-	-	-	-	-	air
zinc rougher - 30 seconds	10.0	1200	none	5 min	SIPX	50	air
zinc rougher - 1 minute	10.0	-	-	-	-	-	air
zinc rougher - 2 minutes	10.0	-	-	-	-	-	air
zinc scavenger - 30 seconds	10.0	-	-	-	SIPX	30	air
zinc scavenger - 1 minute	10.0	-	-	-	-	-	air
zinc scavenger II -	10.0	-	-	-	-	-	air

GRINDING CONDITIONS:

30 minutes. mild steel charge

1200 g/t zinc sulphate

10-102 Collectorless flotation in nitrogen, followed by bulk copper,lead flotation and zinc flotation in nitrogen

sample reference	SOLIDS MASS BALANCE sample weight	mass pull sample	mass pull total	COPPER MASS BALANCE copper assay	copper units	copper recovery stage	copper recovery total	LEAD MASS BALANCE lead assay	lead units	lead recovery stage	lead recovery total
collectorless rougher - 2 minutes	56.39	5.78%	5.78%	0.54	0.031	9.30%	9.30%	6.34	0.366	11.74%	11.74%
collectorless scavenger - 2 minutes	25.78	2.64%	8.42%	0.71	0.019	5.59%	14.90%	5.04	0.133	4.26%	16.00%
zinc rougher - time 30 seconds	35.15	3.60%	12.02%	1.20	0.043	12.89%	27.78%	7.52	0.271	8.68%	24.68%
zinc rougher - time 1 minute	38.09	3.90%	15.93%	1.12	0.044	13.03%	40.82%	9.20	0.359	11.50%	36.18%
zinc rougher - time 2 minutes A	40.70	4.17%	20.10%	0.90	0.038	11.19%	52.01%	8.86	0.370	11.84%	48.02%
zinc rougher - time 2 minutes B	13.86	1.42%	21.52%	0.90	0.013	3.81%	55.82%	6.06	0.086	2.76%	50.77%
zinc scavenger - time 30 seconds	99.34	10.18%	31.70%	0.50	0.051	15.18%	71.00%	6.04	0.615	19.70%	70.47%
zinc scavenger - time 1 minute	54.57	5.59%	37.30%	0.41	0.023	6.84%	77.83%	[illegible]	0.172	5.52%	75.99%
zinc scavenger - time 2 minutes A	66.84	6.85%	44.15%	0.25	0.017	5.11%	82.94%	2.00	0.137	4.39%	80.37%
zinc scavenger - time 2 minutes B	9.04	0.93%	45.07%	0.25	0.002	0.69%	83.63%	2.12	0.020	0.63%	81.00%
final tails	535.90	54.93%	100.00%	0.10	0.055	16.37%	100.00%	1.08	0.593	19.00%	100.00%
reconstituted feed	975.66				0.335	100.00%			3.125	100.00%	

sample reference	ZINC MASS BALANCE zinc assay	zinc units	zinc recovery stage	zinc recovery total	IRON MASS BALANCE iron assay	iron units	iron recovery stage	iron recovery total
collectorless rougher - 2 minutes	7.08	0.409	5.69%	5.69%	34.20	1.977	7.05%	7.05%
collectorless scavenger - 2 minutes	8.19	0.216	3.01%	8.69%	32.70	0.864	3.08%	10.13%
zinc rougher - time 30 seconds	37.99	1.365	18.97%	27.67%	11.40	0.411	1.46%	11.60%
zinc rougher - time 1 minute	30.90	1.206	16.76%	44.43%	15.30	0.597	2.13%	13.73%
zinc rougher - time 2 minutes A	26.50	1.105	15.36%	59.79%	18.70	0.780	2.78%	16.51%
zinc rougher - time 2 minutes B	22.10	0.314	4.36%	64.15%	21.20	0.301	1.07%	17.58%
zinc scavenger - time 30 seconds	17.50	1.782	24.76%	88.91%	28.90	2.943	10.50%	28.09%
zinc scavenger - time 1 minute	5.40	0.302	4.20%	93.11%	39.00	2.181	7.78%	35.86%
zinc scavenger - time 2 minutes A	2.40	0.164	2.28%	95.39%	42.00	2.877	10.26%	46.12%
zinc scavenger - time 2 minutes B	2.61	0.024	0.34%	95.73%	41.50	0.385	1.37%	47.49%
final tails	0.56	0.308	4.27%	100.00%	26.80	14.720	52.51%	100.00%
reconstituted feed		7.197	100.00%			28.036	100.00%	

TEST SUMMARY:

	sample weight	mass pull sample	mass pull total	copper assay %	recovery stage	recovery total	lead assay %	recovery stage	recovery total	zinc assay %	recovery stage	recovery total	iron assay %	recovery stage	recovery total
collectorless flotation	82.17	8.42%	8.42%	0.59	14.90%	14.90%	5.93	16.00%	16.00%	7.43	8.69%	8.69%	33.73	10.13%	10.13%
zinc rougher flotation	127.80	13.10%	21.52%	1.05	40.92%	55.82%	8.29	34.77%	50.77%	30.47	55.46%	64.15%	15.95	7.45%	17.58%
zinc scavenger flotation time 0-1.5 min	153.91	15.77%	37.30%	0.47	22.01%	77.83%	4.99	25.21%	75.99%	13.21	28.96%	93.11%	32.08	18.28%	35.86%
zinc scavenger flotation time 1.5min+	75.88	7.78%	45.07%	0.25	5.80%	83.63%	2.01	5.02%	81.00%	2.43	2.62%	95.73%	41.94	11.63%	47.49%
final flotation tails	535.90	54.93%	100.00%	0.10	16.37%	100.00%	1.08	19.00%	100.00%	0.56	4.27%	100.00%	26.80	52.51%	100.00%

10-103 Collectorless flotation then zinc flotation in nitrogen.

FLOTATION CONDITIONS

sample reference	pH	activator added g/t	Pre-conditioning gas	Pre-conditioning time	collector type	collector addition g/t	flotation gas
collectorless rougher - 2 minutes	8.0	-	air	10 min	-	-	air
collectorless scavenger - 2 minutes	8.0	-	-	-	-	-	air
zinc rougher - 30 second	10.0	1200	nitrogen	20 min	SIPX	50	nitrogen
zinc rougher - 1 minute	10.0	-	-	-	-	-	nitrogen
zinc rougher - 2 minutes A	10.0	-	-	-	-	-	nitrogen
zinc rougher - 2 minutes B	10.0	-	-	-	-	-	nitrogen
zinc scavenger - 30 seconds	10.0	-	-	-	SIPX	30	nitrogen
zinc scavenger - 1 minute	10.0	-	-	-	-	-	nitrogen
zinc scavenger - 2 minutes A	10.0	-	-	-	-	-	nitrogen
zinc scavenger - 2 minutes B	10.0	-	-	-	-	-	nitrogen

GRINDING CONDITIONS:

30 minutes, stainless steel charge

1200 g/t zinc sulphate

10-103 - Collectorless flotation then zinc flotation in nitrogen.

test number 224 sample reference	SOLIDS MASS BALANCE sample weight	mass pull sample	mass pull total	COPPER MASS BALANCE copper assay	copper units	copper recovery stage	copper recovery total	LEAD MASS BALANCE lead assay	lead units	lead recovery stage	lead recovery total	ZINC MASS BALANCE zinc assay	zinc units	zinc recovery stage	zinc recovery total	IRON MASS BALANCE iron assay	iron units	iron recovery stage	iron recovery total
collectorless rougher - 2 minutes	68.26	6.78%	6.78%	0.61	0.041	12.47%	12.47%	6.16	0.418	13.11%	13.11%	7.36	0.499	7.00%	7.00%	34.00	2.306	8.14%	8.14%
collectorless scavenger - 2 minutes	24.48	2.43%	9.21%	0.81	0.020	5.94%	18.41%	5.14	0.125	3.92%	17.03%	9.07	0.221	3.09%	10.09%	32.40	0.780	2.78%	10.93%
zinc rougher - time 30 seconds	74 89	7.44%	16.66%	0.92	0.068	20.64%	39.05%	9.14	0.680	21.34%	38.37%	35.60	2.649	37.14%	47.23%	13.00	0.967	3.42%	14.34%
zinc rougher - time 1 minute	67.36	6.69%	23.35%	0.86	0.058	17.35%	56.40%	8.76	0.586	18.40%	56.77%	27.90	1.867	26.18%	73.40%	18.00	1.205	4.25%	18.59%
zinc rougher - time 2 minutes A	50.33	5.00%	29 14%	0.74	0.043	12.93%	69.33%	6.66	0.386	12.11%	68.88%	17.60	1.020	14.30%	87.70%	26.00	1.553	5.48%	24.08%
zinc rougher - time 2 minutes B	21.18	2.10%	31.25%	0.59	0.012	3.74%	73.08%	5.60	0.105	3.30%	72.18%	10.20	0.215	3.01%	90.71%	31.00	0.652	2.30%	26.38%
zinc scavenger - time 30 seconds	43.53	4.33%	35.57%	0.54	0.023	7.04%	80.12%	5.20	0.220	7.17%	79.35%	7.15	0.309	4.34%	95.05%	35.30	1.527	5.39%	31.77%
zinc scavenger - time 1 minute	26.83	2.67%	38.24%	0.39	0.010	3.13%	83.25%	3.58	0.095	2.99%	82.34%	3.14	0.084	1.17%	96.22%	38.00	1.013	3.58%	35.35%
zinc scavenger - time 2 minutes A	19.14	1.90%	40.14%	0.30	0.006	1.72%	84.97%	2.78	0.053	1.66%	84.00%	2.24	0.043	0.60%	96.82%	38.30	0.720	2.57%	37.92%
zinc scavenger - time 2 minutes B	11.64	1.16%	41.30%	0.25	0.003	0.87%	85.84%	2.46	0.028	0.89%	84.90%	1.86	0.022	0.30%	97.12%	38.00	0.439	1.55%	39.47%
final tails	590.80	58.70%	100.00%	0.08	0.047	14.16%	100.00%	0.82	0.481	15.10%	100.00%	0.35	0.205	2.88%	100.00%	29.20	17.141	60.53%	100.00%
reconstituted feed	1006.44				0.332	100.00%			3.187	100.00%			7.133	100.00%			28.320	100.00%	

TEST SUMMARY:	sample weight	mass pull sample	mass pull total	copper assay %	recovery stage	recovery total	lead assay %	recovery stage	recovery total	zinc assay %	recovery stage	recovery total	iron assay %	recovery stage	recovery total
collectorless flotation	92.74	9.21%	9.21%	0.66	18.41%	18.41%	5.89	17.03%	17.03%	7.81	10.09%	10.09%	33.58	10.93%	10.93%
zinc rougher flotation	221.76	22.03%	31.25%	0.82	54.66%	73.08%	7.98	55.15%	72.18%	26.10	80.62%	90.71%	19.07	15.46%	26.38%
zinc scavenger flotation time 0-1.5 min	70.36	6.99%	38.24%	0.48	10.18%	83.25%	4.63	10.16%	82.34%	5.62	5.51%	96.22%	36.33	8.97%	35.35%
zinc scavenger flotation time 1.5min+	30.78	3.06%	41.30%	0.20	2.59%	85.84%	2.66	2.55%	84.90%	2.10	0.90%	97.12%	38.19	4.12%	39.47%
final flotation tails	590.80	58.70%	100.00%	0.08	14.15%	100.00%	0.82	15.10%	100.00%	0.35	2.89%	100.00%	29.20	60.53%	100.00%

10-104 Collectorless flotation then zinc flotation in air.

FLOTATION CONDITIONS

sample reference	pH	activator added g/t	Pre-conditioning gas	Pre-conditioning time	collector type	collector addition g/t	flotation gas
collectorless rougher - 2 minutes	8.0	-	air	10 min	-	-	air
collectorless scavenger - 2 minutes	8.0	-	-	-	-	-	air
zinc rougher - 30 second	10.0	1200	none	5min	SIPX	50	air
zinc rougher - 1 minute	10.0	-	-	-	-	-	air
zinc rougher - 2 minutes A	10.0	-	-	-	-	-	air
zinc rougher - 2 minutes B	10.0	-	-	-	-	-	air
zinc scavenger - 30 seconds	10.0	-	-	-	SIPX	30	air
zinc scavenger - 1 minute	10.0	-	-	-	-	-	air
zinc scavenger - 2 minutes A	10.0	-	-	-	-	-	air
zinc scavenger - 2 minutes B	10.0	-	-	-	-	-	air

GRINDING CONDITIONS:

30 minutes. stainless steel charge

1200 g/t zinc sulphate

10-104 Collectorless flotation then zinc flotation in air.

sample reference	SOLIDS MASS BALANCE sample weight	mass pull sample	mass pull total	COPPER MASS BALANCE copper assay	copper units	copper recovery stage	copper recovery total	LEAD MASS BALANCE lead assay	lead units	lead recovery stage	lead recovery total	ZINC MASS BALANCE zinc assay	zinc units	zinc recovery stage	zinc recovery total	IRON MASS BALANCE iron assay	iron units	iron recovery stage	iron recovery total
bulk rougher time 1.5 minutes	69.06	7.31%	7.31%	2.56	0.187	54.63%	54.63%	24.30	1.776	51.28%	51.28%	7.11	0.520	5.74%	5.74%	24.20	1.769	7.08%	7.08%
bulk scavenger - time 1.5 minutes	64.70	6.85%	14.16%	0.68	0.047	13.59%	68.22%	9.60	0.657	18.98%	70.26%	10.80	0.740	8.17%	13.92%	31.80	2.178	8.72%	15.81%
pyrite rougher - time 30 seconds	44.52	4.71%	18.87%	0.25	0.012	3.44%	71.66%	3.26	0.154	4.44%	74.70%	6.66	0.314	3.47%	17.38%	38.90	1.833	7.34%	23.15%
pyrite rougher - time 1 minute	29.77	3.15%	22.02%	0.32	0.010	2.94%	74.60%	3.85	0.121	3.50%	78.20%	8.46	0.267	2.95%	20.33%	36.50	1.150	4.61%	27.75%
pyrite rougher - time 2 minutes (A)	46.89	4.96%	26.98%	0.28	0.014	4.06%	78.66%	3.31	0.164	4.74%	82.94%	10.80	0.536	5.92%	26.25%	33.70	1.673	6.70%	34.45%
pyrite rougher - time 2 minutes (B)	13.33	1.41%	28.40%	0.23	0.003	0.95%	79.61%	2.63	0.037	1.07%	84.02%	12.20	0.172	1.90%	28.15%	30.10	0.425	1.70%	36.15%
pyrite scavenger - time 1.5 minutes (C)	58.14	6.15%	34.55%	0.08	0.005	1.44%	81.04%	1.02	0.063	1.81%	85.83%	3.86	0.238	2.62%	30.78%	42.00	2.585	10.35%	46.50%
pyrite scavenger - time 1.5 minutes (D)	85.09	9.01%	43.56%	0.08	0.007	2.10%	83.15%	1.11	0.100	2.89%	88.71%	3.38	0.304	3.36%	34.14%	42.60	3.837	15.37%	61.87%
pyrite scavenger - time 1.5 minutes (E)	52.25	5.53%	49.09%	0.09	0.005	1.45%	84.60%	1.02	0.056	1.63%	90.34%	4.12	0.228	2.52%	36.66%	41.50	2.295	9.19%	71.06%
pyrite scavenger - time 1.5 minutes (F)	42.24	4.47%	53.56%	0.08	0.004	1.04%	85.64%	1.08	0.048	1.39%	91.74%	5.54	0.248	2.74%	39.40%	39.60	1.770	7.09%	78.15%
pyrite scavenger - time 1.5 minutes (G)	24.75	2.62%	56.18%	0.09	0.002	0.69%	86.33%	1.13	0.030	0.85%	92.59%	8.56	0.224	2.48%	41.88%	34.90	0.914	3.66%	81.82%
zinc rougher time 30 seconds	15.99	1.69%	57.87%	0.20	0.003	0.99%	87.32%	0.75	0.013	0.37%	92.96%	50.00	0.846	9.35%	51.23%	9.47	0.160	0.64%	82.46%
zinc rougher - time 1 minute	18.63	1.97%	59.84%	0.22	0.004	1.27%	88.59%	0.78	0.015	0.44%	93.40%	48.90	0.964	10.66%	61.88%	9.71	0.191	0.77%	83.22%
zinc rougher time 2 minutes	31.75	3.36%	63.20%	0.19	0.006	1.86%	90.45%	0.75	0.025	0.73%	94.13%	46.90	1.576	17.42%	79.30%	10.20	0.343	1.37%	84.60%
zinc scavenger - time 1 minute	19.67	2.08%	65.28%	0.24	0.005	1.46%	91.91%	0.95	0.020	0.57%	94.70%	39.60	0.824	9.11%	88.41%	13.30	0.277	1.11%	85.71%
zinc scavenger - time 2 minutes	18.96	2.01%	67.29%	0.24	0.005	1.41%	93.32%	1.16	0.023	0.67%	95.37%	31.90	0.640	7.07%	95.48%	16.00	0.321	1.29%	86.99%
final tails	309.03	32.71%	100.00%	0.07	0.023	6.68%	100.00%	0.49	0.160	4.63%	100.00%	1.25	0.409	4.52%	100.00%	9.93	3.248	13.01%	100.00%
test feed (reconstituted)	944.77				0.343	100.00%			3.464	100.00%			9.050	100.00%			24.969	100.00%	

TEST SUMMARY:	sample weight	mass pull sample	mass pull total	copper assay %	copper recovery stage	copper recovery total	lead assay %	lead recovery stage	lead recovery total	zinc assay %	zinc recovery stage	zinc recovery total	zinc assay %	recovery stage	recovery total
bulk flotation	133.76	14.16%	14.16%	1.65	68.22%	68.22%	17.19	70.26%	70.26%	8.89	13.92%	13.92%	27.88	15.81%	15.81%
pyrite rougher flotation in air	134.51	14.24%	28.40%	0.27	11.39%	79.61%	3.35	13.75%	84.02%	9.05	14.24%	28.15%	35.68	20.35%	36.15%
pyrite scavenger flotation in nitrogen	262.47	27.78%	56.18%	0.08	6.73%	86.33%	1.07	8.58%	92.59%	4.47	13.72%	41.88%	41.04	45.66%	81.82%
zinc rougher flotation	66.37	7.02%	63.20%	0.20	4.12%	90.45%	0.76	1.54%	94.13%	48.21	37.42%	79.30%	9.89	2.78%	84.60%
zinc scavenger flotation	38.63	4.09%	67.29%	0.24	2.86%	93.32%	1.05	1.24%	95.37%	35.82	16.18%	95.48%	14.63	2.39%	86.99%
final tails	309.03	32.71%	100.00%	0.07	6.68%	100.00%	0.49	4.63%	100.00%	1.25	4.52%	100.00%	9.93	13.01%	100.00%

10-201 Bulk copper, lead flotation in air, pyrite flotation in air and nitrogen, zinc flotation in air.

FLOTATION CONDITIONS

sample reference	pH	activator added g/t	pre-conditioning		collector		flotation gas
			gas	time	type	addition g/t	
bulk rougher - 1.5 minute A	8.5	-	air	10 min	SIPX	50	air
bulk rougher - 1.5 minute B	8.5	-	-	-	SIPX	30	air
pyrite rougher - 30 seconds	8.5	-	-	-	-	-	air
pyrite rougher - 1 minute	8.5	-	-	-	-	-	air
pyrite rougher - 2 minutes A	8.5	-	-	-	-	-	air
pyrite rougher - 2 minutes B	8.5	-	-	-	-	-	air
pyrite scavenger - 1.5 minutes C	8.5	-	nitrogen	20 min	-	-	nitrogen
pyrite scavenger - 1.5 minutes D	8.5	-	-	-	-	-	nitrogen
pyrite scavenger - 1.5 minutes E	8.5	-	-	-	-	-	nitrogen
pyrite scavenger - 1.5 minutes F	8.5	-	-	-	-	-	nitrogen
pyrite scavenger - 1.5 minutes G	8.5	-	-	-	-	-	nitrogen
zinc rougher - 30 second	10.0	1200	none	5 min	SIPX	50	air
zinc rougher - 1 minute	10.0	-	-	-	-	-	air
zinc rougher - 2 minutes A	10.0	-	-	-	-	-	air
zinc scavenger - 1 minute	10.0	-	-	-	SIPX	30	air
zinc scavenger - 2 minutes	10.0	-	-	-	-	-	air

GRINDING CONDITIONS:

30 minutes, mild steel charge

1200 g/t zinc sulphate

10-201 Bulk copper,lead flotation in air, pyrite flotation in air and nitrogen, zinc flotation in air.

sample reference	sample weight	mass pull sample	mass pull total	copper assay	copper units	copper recovery stage	copper recovery total	lead assay	lead units	lead recovery stage	lead recovery total	zinc assay	zinc units	zinc recovery stage	zinc recovery total	iron assay	iron units	iron recovery stage	iron recovery total
	SOLIDS MASS BALANCE			**COPPER MASS BALANCE**				**LEAD MASS BALANCE**				**ZINC MASS BALANCE**				**IRON MASS BALANCE**			
bulk rougher - time 1.5 minutes	91.26	9.59%	9.59%	2.02	0.194	57.53%	57.53%	20.20	1.936	59.60%	59.60%	8.16	0.782	8.83%	8.83%	26.50	2.540	10.18%	10.18%
bulk scavenger - time 1.5 minutes	59.80	6.28%	15.87%	0.58	0.036	10.82%	68.36%	7.47	0.469	14.44%	74.04%	10.60	0.666	7.52%	16.35%	33.20	2.085	8.36%	18.53%
pyrite rougher - time 30 seconds	56.17	5.90%	21.77%	0.20	0.012	3.51%	71.86%	2.54	0.150	4.61%	78.65%	5.88	0.347	3.92%	20.27%	39.70	2.342	9.38%	27.92%
pyrite rougher - time 1 minute	26.49	2.78%	24.55%	0.28	0.008	2.31%	74.18%	3.44	0.096	2.95%	81.60%	8.88	0.247	2.79%	23.06%	35.70	0.993	3.98%	31.90%
pyrite rougher - time 2 minutes (A)	22.70	2.38%	26.93%	0.29	0.007	2.05%	76.23%	3.30	0.079	2.42%	84.02%	11.40	0.272	3.07%	26.13%	31.90	0.761	3.05%	34.95%
pyrite rougher - time 2 minutes (B)	16.28	1.71%	28.64%	0.27	0.005	1.37%	77.60%	3.79	0.065	1.99%	86.02%	12.40	0.212	2.39%	28.52%	29.50	0.504	2.02%	36.97%
pyrite scavenger - time 1.5 minutes (C)	3.65	0.38%	29.03%	0.32	0.001	0.36%	77.97%	2.95	0.011	0.35%	86.37%	11.00	0.045	0.51%	29.03%	26.60	0.102	0.41%	37.37%
pyrite scavenger - time 1.5 minutes (D)	0.00	0.00%	29.03%	0.00	0.000	0.00%	77.97%	0.00	0.000	0.00%	86.37%	0.00	0.000	0.00%	29.03%	0.00	0.000	0.00%	37.37%
pyrite scavenger - time 1.5 minutes (E)	0.00	0.00%	29.03%	0.00	0.000	0.90%	77.97%	0.00	0.000	0.00%	86.37%	0.00	0.000	0.00%	29.03%	0.00	0.000	0.09%	37.37%
pyrite scavenger - time 1.5 minutes (F)	0.00	0.00%	29.03%	0.00	0.000	0.00%	77.97%	0.00	0.000	0.00%	86.37%	0.00	0.000	0.00%	29.03%	0.00	0.000	0.00%	37.37%
pyrite scavenger - time 1.5 minutes (G)	0.00	0.00%	29.03%	0.00	0.000	0.00%	77.97%	0.00	0.000	0.00%	86.37%	0.00	0.000	0.00%	29.03%	0.00	0.000	0.00%	37.37%
zinc rougher - time 30 seconds	18.89	1.98%	31.01%	0.49	0.010	2.89%	80.86%	1.17	0.023	0.71%	87.08%	46.40	0.921	10.39%	39.43%	17.10	0.339	1.36%	38.73%
zinc rougher - time 1 minute	22.76	2.39%	33.40%	0.20	0.005	1.42%	82.28%	1.03	0.025	0.76%	87.84%	46.00	1.100	12.42%	51.84%	12.90	0.308	1.24%	39.97%
zinc rougher - time 2 minutes	38.47	4.04%	37.44%	0.25	0.010	3.00%	85.28%	1.12	0.045	1.39%	89.23%	41.70	1.685	19.03%	70.87%	15.10	0.610	2.44%	42.41%
zinc rougher - time 2 minutes	23.84	2.50%	39.95%	0.17	0.004	1.26%	86.54%	1.14	0.029	0.88%	90.11%	36.40	0.912	10.29%	81.16%	18.10	0.453	1.82%	44.23%
zinc scavenger - time 1 minute	9.95	1.05%	40.99%	0.18	0.002	0.56%	87.10%	1.10	0.011	0.35%	90.46%	35.40	[illegible]	4.18%	85.34%	19.20	0.201	0.80%	45.03%
zinc scavenger - time 2 minutes	15.44	1.62%	42.62%	0.20	0.003	0.96%	88.07%	1.06	0.017	0.53%	90.99%	30.90	0.501	5.66%	90.99%	21.50	0.349	1.40%	46.43%
final tails	546.30	57.38%	100.00%	0.07	0.040	11.93%	100.90%	0.51	0.293	9.01%	100.00%	1.39	0.798	9.01%	100.00%	23.30	13.378	53.57%	100.00%
test feed (reconstituted)	952.00				0.337	100.00%			3.249	100.00%			8.857	100.00%		35.70	24.960	100.00%	

TEST SUMMARY:	sample weight	mass pull sample	mass pull total	copper assay %	copper recovery stage	copper recovery total	lead assay %	lead recovery stage	lead recovery total	zinc assay %	zinc recovery stage	zinc recovery total	iron assay %	iron recovery stage	iron recovery total
bulk flotation	151.06	15.87%	15.87%	1.45	68.36%	68.36%	15.16	74.04%	74.04%	9.13	16.35%	16.35%	29.15	18.53%	18.53%
pyrite rougher flotation in air	121.66	12.78%	28.64%	0.24	9.25%	77.60%	3.05	11.98%	86.02%	8.44	12.17%	28.52%	36.01	18.43%	36.97%
pyrite scavenger flotation in nitrogen	3.65	0.38%	29.03%	0.32	0.36%	77.97%	2.95	0.35%	86.37%	11.00	0.51%	29.03%	26.60	0.41%	37.37%
zinc rougher flotation	103.96	10.92%	39.95%	0.26	8.58%	86.54%	1.11	3.74%	90.11%	42.28	52.13%	81.16%	15.67	6.86%	44.23%
zinc scavenger flotation	25.39	2.67%	42.62%	0.19	1.52%	88.07%	1.08	0.88%	90.99%	32.66	9.84%	90.99%	20.60	2.20%	46.43%
final tails	546.30	57.38%	100.00%	0.07	11.93%	100.00%	0.51	9.01%	100.00%	1.39	9.01%	100.00%	23.30	53.57%	100.00%

10-202 Bulk copper, lead flotation in air, pyrite flotation in air and zinc flotation in air.

F L O T A T I O N   C O N D I T I O N S

sample reference	pH	activator added g/t	Pre-conditioning gas	Pre-conditioning time	collector type	collector addition g/t	flotation gas
bulk rougher - 1.5 minute A	8.5	-	air	10 min	SIPX	50	air
bulk rougher - 1.5 minute B	8.5	-	-	-	SIPX	30	air
pyrite rougher - 30 seconds	8.5	-	-	-	-	-	air
pyrite rougher - 1 minute	8.5	-	-	-	-	-	air
pyrite rougher - 2 minutes A	8.5	-	-	-	-	-	air
pyrite rougher - 2 minutes B	8.5	-	-	-	-	-	air
pyrite scavenger - 1.5 minutes C	8.5	-	-	-	-	-	air
zinc rougher - 30 second	10.0	1200	none	5 min	SIPX	50	air
zinc rougher - 1 minute	10.0	-	-	-	-	-	air
zinc rougher - 2 minutes A	10.0	-	-	-	-	-	air
zinc rougher - 2 minutes B	10.0	-	-	-	-	-	air
zinc scavenger - 1 minute	10.0	-	-	-	SIPX	30	air
zinc scavenger - 2 minutes	10.0	-	-	-	-	-	air

GRINDING CONDITIONS:

30 minutes, mild steel charge

1200 g/t zinc sulphate

10-202 Bulk copper,lead flotation in air, pyrite flotation in air and zinc flotation in air.

sample reference	SOLIDS MASS BALANCE sample weight	mass pull sample	mass pull total	COPPER MASS BALANCE copper assay	copper units	copper recovery stage	copper recovery total	LEAD MASS BALANCE lead assay	lead units	lead recovery stage	lead recovery total	ZINC MASS BALANCE zinc assay	zinc units	zinc recovery stage	zinc recovery total	IRON MASS BALANCE iron assay	iron units	iron recovery stage	iron recovery total
bulk rougher time 1.5 minutes	73.78	7.27%	7.27%	2.65	0.193	55.45%	55.45%	22.80	1.659	47.64%	47.64%	6.49	0.472	5.22%	5.22%	25.90	1.884	7.48%	7.48%
bulk scavenger time 1.5 minutes	91.19	8.99%	16.26%	0.57	0.051	14.74%	70.19%	8.39	0.754	21.67%	69.31%	9.57	0.860	9.52%	14.75%	35.60	3.201	12.70%	20.18%
pyrite rougher - time 30 seconds	73.42	7.24%	23.50%	0.20	0.014	4.16%	74.35%	2.78	0.201	5.78%	75.09%	5.34	0.387	4.28%	19.03%	40.00	2.895	11.49%	31.67%
pyrite rougher time 1 minute	69.40	6.84%	30.35%	0.20	0.014	3.94%	78.29%	2.68	0.183	5.27%	80.35%	6.11	0.418	4.63%	23.65%	38.70	2.688	10.51%	42.18%
pyrite rougher time 2 minutes (A)	35.75	3.52%	33.87%	0.25	0.009	2.57%	80.82%	3.04	0.107	3.08%	83.43%	8.91	0.314	3.48%	27.13%	35.30	1.244	4.94%	47.12%
pyrite rougher time 2 minutes (B)	11.84	1.17%	35.04%	0.25	0.003	0.84%	81.66%	3.07	0.036	1.03%	84.46%	11.60	0.138	1.52%	28.65%	30.90	0.361	1.43%	48.55%
pyrite scavenger - time 0.5 minutes (C)	40.93	4.04%	39.07%	0.09	0.004	1.04%	82.71%	1.29	0.052	1.50%	85.96%	3.69	0.149	1.65%	30.30%	42.10	1.699	6.74%	55.30%
pyrite scavenger time 1 minute (D)	88.39	8.71%	47.79%	0.09	0.008	2.25%	84.96%	1.12	0.098	2.80%	88.76%	4.19	0.365	4.04%	34.34%	41.60	3.625	14.39%	69.68%
pyrite scavenger - time 2 minutes (E)	55.55	5.48%	53.26%	0.09	0.005	1.42%	86.38%	1.17	0.064	1.84%	90.60%	6.24	0.342	3.78%	38.12%	38.50	2.109	8.37%	78.05%
pyrite scavenger time 2 minutes (F)	20.32	2.00%	55.27%	0.10	0.002	0.58%	86.96%	1.37	0.027	0.79%	91.39%	9.03	0.181	2.00%	40.13%	34.30	0.687	2.73%	80.78%
pyrite scavenger time 2 minutes (G)	15.62	1.54%	56.81%	0.11	0.002	0.49%	87.44%	1.43	0.022	0.63%	92.02%	11.10	0.171	1.89%	42.02%	31.30	0.482	1.91%	82.69%
pyrite scavenger time 2 minutes (H)	19.22	1.89%	58.70%	0.10	0.002	0.55%	87.99%	1.67	0.032	0.91%	92.93%	11.30	0.214	2.37%	44.39%	30.50	0.578	2.29%	84.99%
zinc rougher time 30 seconds	20.85	2.06%	60.76%	0.18	0.004	1.06%	89.05%	0.54	0.011	0.32%	93.25%	55.60	1.143	12.65%	57.04%	7.83	0.161	0.64%	85.63%
zinc rougher time 1 minute	31.67	3.12%	63.88%	0.19	0.006	1.71%	90.76%	0.63	0.020	0.57%	93.81%	52.10	1.627	18.00%	75.04%	9.17	0.286	1.14%	86.76%
zinc rougher time 2 minutes	21.96	2.17%	66.05%	0.22	0.005	1.37%	92.13%	0.82	0.018	0.51%	94.32%	45.80	0.992	10.97%	86.02%	11.20	0.242	0.96%	87.73%
zinc rougher time 2 minutes	16.97	1.67%	67.72%	0.24	0.004	1.16%	93.29%	1.08	0.018	0.52%	94.84%	35.60	0.596	6.59%	92.61%	14.40	0.241	0.96%	88.68%
zinc scavenger time 2 minutes A	18.55	1.83%	69.55%	0.27	0.005	1.42%	94.71%	1.41	0.026	0.74%	95.58%	19.40	0.355	3.93%	96.54%	20.30	0.371	1.47%	90.16%
zinc scavenger time 2 minutes B	17.91	1.77%	71.31%	0.23	0.004	1.17%	95.87%	1.56	0.028	0.79%	96.37%	7.81	0.138	1.53%	98.06%	19.60	0.346	1.37%	91.53%
final tails	290.96	28.69%	100.00%	0.05	0.014	4.13%	100.00%	0.44	0.126	3.63%	100.00%	0.61	0.175	1.94%	100.00%	7.44	2.134	8.47%	100.00%
test feed (reconstituted)	1014.28				0.346	100.00%			3.481	100.00%			9.035	100.00%			25.195	100.00%	

TEST SUMMARY:

	sample weight	mass pull sample	mass pull total	copper assay %	recovery stage	recovery total	lead assay %	recovery stage	recovery total	zinc assay %	recovery stage	recovery total	iron assay %	recovery stage	recovery total
bulk flotation	164.97	16.26%	16.26%	1.50	70.19%	70.19%	14.83	69.31%	69.31%	8.19	14.75%	14.75%	31.26	20.18%	20.18%
pyrite rougher flotation in air	190.41	18.77%	35.04%	0.21	11.47%	81.66%	2.81	15.15%	84.46%	6.69	13.91%	28.65%	38.08	28.37%	48.55%
pyrite scavenger flotation in nitrogen	240.03	23.67%	58.70%	0.09	6.33%	87.99%	1.75	8.47%	92.93%	6.01	15.74%	44.39%	38.79	36.43%	84.99%
zinc rougher flotation	74.08	9.07%	67.72%	0.20	5.30%	93.29%	0.66	1.91%	94.84%	51.22	48.22%	92.61%	9.39	3.69%	88.68%
zinc scavenger flotation	36.46	3.59%	71.31%	0.25	2.59%	95.87%	1.48	1.53%	96.37%	13.71	5.45%	98.06%	19.96	2.05%	91.53%
final tails	290.96	28.69%	100.00%	0.05	4.13%	100.00%	0.44	3.63%	100.00%	0.61	1.94%	100.00%	7.44	8.47%	100.00%

10-203 Bulk copper,lead flotation in air, pyrite flotation in air then nitrogen and zinc flotation in air.

F L O T A T I O N   C O N D I T I O N S

sample reference	pH	activator added g/t	Pre-conditioning gas	Pre-conditioning time	collector type	collector addition g/t	flotation gas
bulk rougher - 1.5 minute A	8.5	-	air	10 min	SIPX	50	air
bulk rougher - 1.5 minute B	8.5	-	-	-	SIPX	30	air
pyrite rougher - 30 seconds	8.5	-	-	-	-	-	air
pyrite rougher - 1 minute	8.5	-	-	-	-	-	air
pyrite rougher - 2 minutes A	8.5	-	-	-	-	-	air
pyrite rougher - 2 minutes B	8.5	-	-	-	-	-	air
pyrite scavenger - 30 seconds C	8.5	-	nitrogen	20 min	SIPX	10	nitrogen
pyrite scavenger - 1 minute D	8.5	-	-	-	-	-	nitrogen
pyrite scavenger - 2 minutes E	8.5	-	-	-	-	-	nitrogen
pyrite scavenger - 2 minutes F	8.5	-	-	-	-	-	nitrogen
pyrite scavenger - 2 minutes G	8.5	-	-	-	-	-	nitrogen
pyrite scavenger - 2 minutes H	8.5	-	-	-	-	-	nitrogen
zinc rougher - 30 second	10.0	1200	none	5 min	SIPX	50	air
zinc rougher - 1 minute	10.0	-	-	-	-	-	air
zinc rougher - 2 minutes A	10.0	-	-	-	-	-	air
zinc rougher - 2 minutes B	10.0	-	-	-	-	-	air
zinc scavenger - 1 minute	10.0	-	-	-	SIPX	30	air
zinc scavenger - 2 minutes	10.0	-	-	-	-	-	air

GRINDING CONDITIONS:

30 minutes, mild steel charge

1200 g/t zinc sulphate

10-203 Bulk copper,lead flotation in air, pyrite flotation in air then nitrogen and zinc flotation in air.

sample reference	SOLIDS MASS BALANCE: sample weight	mass pull: sample	mass pull: total	COPPER MASS BALANCE: copper assay	copper units	copper recovery: stage	copper recovery: total	LEAD MASS BALANCE: lead assay	lead units	lead recovery: stage	lead recovery: total	ZINC MASS BALANCE: zinc assay	zinc units	zinc recovery: stage	zinc recovery: total	IRON MASS BALANCE: iron assay	iron units	iron recovery: stage	iron recovery: total
bulk rougher - time 2 minutes	56.21	5.53%	5.53%	2.88	0.159	49.28%	49.28%	5.22	0.209	8.37%	8.37%	6.13	0.339	4.18%	4.18%	32.90	1.820	6.44%	6.44%
bulk scavenger - time 2 minutes	132.35	13.03%	18.56%	0.67	0.087	26.99%	76.27%	13.60	1.772	51.35%	59.73%	7.05	0.918	11.31%	15.49%	31.00	4.039	14.29%	20.73%
pyrite rougher - time 1 minute (A)	32.30	3.18%	21.74%	0.19	0.006	1.07%	78.14%	7.70	0.245	7.10%	66.02%	9.20	0.293	3.60%	19.09%	31.90	1.014	3.59%	24.32%
pyrite rougher - time 1 minute (B)	29.74	2.93%	24.67%	0.14	0.004	1.27%	79.41%	4.10	0.120	3.48%	70.30%	7.25	0.212	2.61%	21.71%	35.90	1.051	3.72%	28.04%
pyrite rougher - time 1 minute (C)	23.56	2.32%	26.99%	0.11	0.003	0.79%	80.20%	2.40	0.056	1.61%	71.91%	6.64	0.154	1.90%	23.60%	36.30	0.842	2.98%	31.01%
pyrite rougher - time 1 minute (D)	21.05	2.07%	29.06%	0.09	0.002	0.58%	80.77%	1.78	0.037	1.07%	72.98%	6.55	0.136	1.67%	25.27%	35.00	0.725	2.57%	33.58%
pyrite scavenger - time 1 minute (A)	231.58	22.80%	51.85%	0.06	0.014	4.23%	85.00%	1.54	0.351	10.18%	83.16%	2.80	0.638	7.86%	33.13%	42.00	9.756	34.52%	68.10%
pyrite scavenger - time 1 minute (B)	83.03	8.17%	60.03%	0.07	0.006	1.77%	86.77%	1.72	0.141	4.07%	87.23%	4.82	0.394	4.85%	37.99%	40.80	3.335	11.80%	79.90%
pyrite scavenger - time 1 minute (C)	38.06	3.75%	63.77%	0.10	0.004	1.16%	87.93%	1.90	0.071	2.06%	89.30%	8.56	0.321	3.95%	41.94%	35.90	1.345	4.76%	84.65%
zinc rougher time 30 seconds	62.42	6.14%	69.92%	0.18	0.011	3.42%	91.35%	1.12	0.069	1.99%	91.29%	46.10	2.832	34.88%	76.82%	11.90	0.731	2.59%	87.24%
zinc rougher - time 1 minute	33.64	3.31%	73.23%	0.23	0.008	2.36%	93.71%	1.58	0.052	1.52%	92.81%	41.10	1.361	16.76%	93.58%	17.60	0.583	2.06%	89.30%
zinc rougher - time 2 minutes	26.61	2.62%	75.85%	0.23	0.006	1.86%	95.57%	1.92	0.050	1.46%	94.26%	13.20	0.346	4.26%	97.84%	23.10	0.605	2.14%	91.44%
zinc rougher - time 2 minutes (D)	11.20	1.10%	76.95%	0.22	0.002	0.75%	96.32%	2.14	0.024	0.68%	94.95%	4.42	0.049	0.60%	98.44%	23.70	0.261	0.92%	92.37%
zinc scavenger - time 30 seconds	12.48	1.23%	78.18%	0.16	0.002	0.61%	96.93%	1.62	0.020	0.58%	95.53%	1.95	0.024	0.30%	98.74%	27.00	0.332	1.17%	93.54%
zinc scavenger - time 1 minute	9.39	0.92%	79.10%	0.17	0.002	0.49%	97.41%	1.78	0.016	0.48%	96.00%	1.16	0.011	0.13%	98.87%	23.40	0.216	0.77%	94.31%
final tails	212.30	20.90%	100.00%	0.04	0.008	2.59%	100.00%	0.66	0.138	4.00%	100.00%	0.44	0.092	1.13%	100.00%	7.70	1.609	5.69%	100.00%
test feed (reconstituted)	1015.92				0.323	100.00%			3.450	100.00%			8.119	100.00%			20.264	100.00%	

TEST SUMMARY:	sample weight	mass pull: sample	mass pull: total	copper assay %	copper recovery: stage	copper recovery: total	lead assay %	lead recovery: stage	lead recovery: total	zinc assay %	zinc recovery: stage	zinc recovery: total	iron assay %	iron recovery: stage	iron recovery: total
bulk flotation	188.56	18.56%	18.56%	1.33	76.27%	76.27%	11.10	59.73%	59.73%	6.78	15.49%	15.49%	31.57	20.73%	20.73%
pyrite rougher flotation in air	106.65	10.50%	29.06%	0.14	4.50%	80.77%	4.36	13.26%	72.98%	7.57	9.78%	25.27%	34.60	12.85%	33.58%
pyrite scavenger flotation in nitrogen	352.67	34.71%	63.77%	0.07	7.16%	87.93%	1.62	16.31%	89.30%	3.90	16.66%	41.94%	41.58	51.07%	84.65%
zinc rougher flotation	96.06	9.46%	73.23%	0.20	5.78%	93.71%	1.28	3.51%	92.81%	44.35	51.65%	93.58%	13.90	4.65%	89.30%
zinc scavenger flotation	57.68	5.87%	79.10%	0.20	3.71%	97.41%	1.80	3.20%	96.00%	10.06	5.29%	98.87%	24.00	5.00%	94.31%
final tails	212.30	20.90%	100.00%	0.04	2.59%	100.00%	0.66	4.00%	100.00%	0.44	1.13%	100.00%	7.70	5.69%	100.00%

10-204 Bulk copper,lead flotation in air, pyrite flotation in nitrogen and zinc flotation in air.

F L O T A T I O N   C O N D I T I O N S

sample reference	pH	activator added g/t	Pre-conditioning gas	Pre-conditioning time	collector type	collector addition g/t	flotation gas
bulk rougher - time 2 minutes	8.5	-	air	10 min	SIPX	50	air
bulk scavenger - time 2 minutes	8.5	-	-	-	SIPX	30	air
pyrite rougher - time 1 minute (A)	8.5	-	nitrogen	4 min	-	-	nitrogen
pyrite rougher - time 1 minute (B)	8.5	-	nitrogen	4 min	-	-	nitrogen
pyrite rougher - time 1 minute (C)	8.5	-	nitrogen	4 min	-	-	nitrogen
pyrite rougher - time 1 minute (D)	8.5	-	nitrogen	4 min	-	-	nitrogen
pyrite scavenger - time 1 minute (A)	8.5	-	-	-	SIPX	10	nitrogen
pyrite scavenger - time 1 minute (B)	8.5	-	-	-	-	-	nitrogen
pyrite scavenger - time 1 minute (C)	8.5	-	-	-	-	-	nitrogen
zinc rougher - time 30 seconds	10.0	1200	none	5 min	SIPX	50	air
zinc rougher - time 1 minute	10.0	-	-	-	-	-	air
zinc rougher - time 2 minutes	10.0	-	-	-	-	-	air
zinc rougher - time 2 minutes (B)	10.0	-	-	-	-	-	air
zinc scavenger - time 30 seconds	10.0	-	-	-	SIPX	30	air
zinc scavenger - time 1 minute	10.0	-	-	-	-	-	air

GRINDING CONDITIONS:

50 minutes, stainless steel charge.

Zinc Sulphate, 1200 g/t

10-204 Bulk copper,lead flotation in air, pyrite flotation in nitrogen and zinc flotation in air.

sample reference	SOLIDS MASS BALANCE sample weight	mass pull sample	mass pull total	COPPER MASS BALANCE copper assay	copper units	copper recovery stage	copper recovery total	LEAD MASS BALANCE lead assay	lead units	lead recovery stage	lead recovery total	ZINC MASS BALANCE zinc assay	zinc units	zinc recovery stage	zinc recovery total	IRON MASS BALANCE iron assay	iron units	iron recovery stage	iron recovery total
bulk rougher - time 1 minute (A)	20.76	2.00%	2.00%	0.93	0.026	7.67%	7.67%	6.48	0.182	5.53%	5.53%	7.27	0.204	2.55%	2.55%	31.70	0.888,	3.17%	3.17%
bulk rougher - time 1 minute (B)	46.54	4.53%	7.34%	3.45	0.156	46.05%	53.72%	6.10	0.277	8.43%	13.96%	3.41	0.155	1.93%	4.48%	36.50	1.655	5.90%	9.07%
bulk rougher - time 1 minute (C)	165.35	16.11%	23.45%	0.33	0.053	15.65%	69.37%	5.54	0.893	27.20%	41.16%	2.75	0.443	5.54%	10.02%	40.30	6.493	23.16%	32.23%
bulk rougher - time 1 minute (D)	216.36	21.08%	44.53%	0.17	0.036	10.55%	79.92%	4.64	0.978	29.81%	70.97%	3.39	0.715	8.94%	18.96%	40.10	8.453	30.15%	62.38%
bulk rougher - time 1 minute (E)	108.21	10.15%	54.68%	0.16	0.016	4.78%	84.70%	3.38	0.343	10.46%	81.43%	7.79	0.791	9.09%	28.06%	36.90	3.707	13.36%	75.74%
zinc rougher - time 30 seconds	80.12	7.81%	62.49%	0.18	0.014	4.14%	88.84%	1.62	0.126	3.85%	85.28%	45.60	3.560	44.53%	73.39%	12.00	0.937	3.34%	79.08%
zinc rougher - time 1 minute	37.36	3.64%	66.13%	0.21	0.008	2.25%	91.09%	1.86	0.068	2.06%	87.34%	31.50	1.147	14.38%	87.73%	16.30	0.593	2.12%	81.20%
zinc rougher - time 2 minutes	37.64	3.67%	69.79%	0.22	0.008	2.38%	93.47%	1.94	0.071	2.17%	89.51%	16.90	0.620	7.75%	95.48%	29.20	1.071	3.82%	85.02%
zinc scavenger - time 30 seconds	23.50	2.29%	72.08%	0.21	0.005	1.42%	94.88%	1.96	0.045	1.37%	90.88%	6.29	0.144	1.80%	97.28%	31.10	0.712	2.54%	87.56%
zinc scavenger - time 1 minute	22.01	2.14%	74.23%	0.21	0.005	1.33%	96.21%	2.42	0.052	1.38%	92.46%	4.00	0.086	1.07%	98.36%	30.50	0.654	2.33%	89.89%
final tails	264.50	25.77%	100.00%	0.05	0.013	3.79%	100.00%	0.96	0.247	7.54%	100.00%	0.51	0.131	1.64%	100.00%	11.00	2.835	10.11%	100.00%
test feed (reconstituted)	1026.35				0.340	100.00%			3.282	100.00%			7.994	100.00%			28.038	100.00%	

TEST SUMMARY:	sample weight	mass pull sample	mass pull total	copper assay %	recovery stage	recovery total	lead assay %	recovery stage	recovery total	zinc assay %	recovery stage	recovery total	iron assay %	recovery stage	recovery total
bulk flotation	561.22	54.68%	54.68%	0.53	84.70%	84.70%	4.89	81.43%	81.43%	4.22	28.06%	28.06%	38.04	75.74%	75.74%
zinc rougher flotation	155.12	15.11%	69.79%	0.20	8.76%	93.47%	1.76	8.09%	89.51%	35.24	66.62%	95.48%	17.21	9.28%	85.02%
zinc scavenger flotation	45.51	4.43%	74.23%	0.21	2.74%	96.21%	2.18	2.95%	92.46%	5.18	2.87%	98.36%	30.81	4.87%	89.89%
final tails	264.50	25.77%	100.00%	0.05	3.79%	100.00%	0.96	7.54%	100.00%	0.51	1.64%	100.00%	11.00	10.11%	100.00%

10-205 Bulk copper,lead,pyrite flotation in nitrogen with stage addition of collector, then zinc flotation in nitrogen.

FLOTATION CONDITIONS

sample reference	pH	activator added g/t	Pre-conditioning gas	Pre-conditioning time	collector type	collector addition g/t	flotation gas
bulk rougher - 1 minute A	8.5	-	nitrogen	3 min	SIPX	20	nitrogen
bulk rougher - 1 minute B	8.5	-	nitrogen	3 min	SIPX	20	nitrogen
bulk rougher - 1 minute C	8.5	-	nitrogen	3 min	SIPX	20	nitrogen
bulk rougher - 1 minute D	8.5	-	nitrogen	3 min	SIPX	20	nitrogen
bulk rougher - 1 minute E	8.5	-	nitrogen	3 min	SIPX	20	nitrogen
zinc rougher - 30 seconds	10.0	1200	none	5 min	SIPX	50	air
zinc rougher - 1 minute	10.0	-	-	-	-	-	air
zinc rougher - 2 minutes	10.0	-	-	-	-	-	air
zinc scavenger - 30 seconds	10.0	-	-	-	SIPX	30	air
zinc scavenger - 1 minute	10.0	-	-	-	-	-	air

GRINDING CONDITIONS:

30 minutes, mild steel charge

1200 g/t zinc sulphate

10-205 Bulk copper,lead,pyrite flotation in nitrogen with stage addition of collector, then zinc flotation in nitrogen.

sample reference	SOLIDS MASS BALANCE sample weight (grams)	mass pull sample	mass pull total	COPPER MASS BALANCE copper assay (%)	copper units	copper recovery stage	copper recovery total
bulk rougher 2 minutes	452.80	44.46%	44.46%	0.53	0.236	71.10%	71.10%
bulk scavenger - 2 minutes	148.94	14.63%	59.09%	0.31	0.045	13.68%	84.77%
zinc rougher time 30 seconds	59.01	5.30%	64.39%	0.17	0.009	2.72%	87.49%
zinc rougher - time 1 minute	25.95	2.55%	66.94%	0.20	0.005	1.54%	89.03%
zinc rougher - time 2 minutes A	31.57	3.10%	70.04%	0.23	0.007	2.15%	91.18%
zinc rougher - time 2 minutes B	0.00	0.00%	70.04%	0.21	0.000	0.00%	91.18%
zinc scavenger - time 30 seconds	25.87	2.54%	72.58%	0.23	0.006	1.76%	92.94%
zinc scavenger - time 1 minute	25.12	2.47%	75.05%	0.24	0.006	1.79%	94.73%
final tails	254.08	24.95%	100.00%	0.07	0.017	5.27%	100.00%
reconstituted feed	1018.34				0.331	100.00%	

sample reference	LEAD MASS BALANCE lead assay (%)	lead units	lead recovery stage	lead recovery total	ZINC MASS BALANCE zinc assay (%)	zinc units	zinc recovery stage	zinc recovery total	IRON MASS BALANCE iron assay (%)	iron units	iron recovery stage	iron recovery total
bulk rougher 2 minutes	5.14	2.285	68.86%	68.86%	4.09	1.819	23.20%	23.20%	39.50	17.563	61.49%	61.49%
bulk scavenger - 2 minutes	3.70	0.541	16.30%	85.16%	8.01	1.172	14.94%	38.14%	36.10	5.280	18.48%	79.97%
zinc rougher time 30 seconds	1.14	0.060	1.82%	86.98%	48.90	2.594	33.08%	71.22%	9.09	0.482	1.69%	81.66%
zinc rougher - time 1 minute	1.54	0.039	1.18%	88.16%	39.10	0.996	12.71%	83.93%	13.30	0.339	1.19%	82.85%
zinc rougher - time 2 minutes A	1.78	0.055	1.66%	89.83%	24.60	0.763	9.73%	93.66%	21.00	0.651	2.28%	85.13%
zinc rougher - time 2 minutes B	2.00	0.000	0.00%	89.83%	1.00	0.000	0.00%	93.66%	0.00	0.000	0.00%	85.13%
zinc scavenger - time 30 seconds	2.00	0.051	1.53%	91.36%	9.44	0.240	3.06%	96.71%	29.20	0.742	2.60%	87.72%
zinc scavenger - time 1 minute	1.92	0.047	1.43%	92.78%	4.98	0.123	1.57%	98.28%	29.90	0.738	2.58%	90.30%
final tails	0.96	0.240	7.22%	100.00%	0.54	0.135	1.72%	100.00%	11.10	2.769	9.70%	100.00%
reconstituted feed		3.319	100.00%			7.840	100.00%			28.564	100.00%	

TEST SUMMARY:	sample weight	mass pull sample	mass pull total	copper assay %	copper recovery stage	copper recovery total	lead assay %	lead recovery stage	lead recovery total	zinc assay %	zinc recovery stage	zinc recovery total	iron assay %	iron recovery stage	iron recovery total
bulk flotation	601.74	59.09%	59.09%	0.48	84.77%	84.77%	4.78	85.16%	85.16%	5.06	38.14%	38.14%	38.66	79.97%	79.97%
zinc rougher flotation	111.53	10.95%	70.04%	0.19	6.41%	91.18%	1.41	4.67%	89.83%	39.74	55.52%	93.66%	13.44	5.15%	85.13%
zinc scavenger flotation time 0-1.5 min	50.99	5.01%	75.05%	0.23	3.55%	94.73%	1.96	2.96%	92.78%	7.24	4.63%	98.28%	29.54	5.18%	90.30%
final flotation tails	254.08	24.95%	100.00%	0.07	5.27%	100.00%	0.96	7.22%	100.00%	0.54	1.72%	100.00%	11.10	9.70%	100.00%

10-206 Bulk Cu,Pb,pyrite flotation in nitrogen, single addition of collector, zinc flotation in nitrogen.

FLOTATION CONDITIONS

sample reference	pH	activator added g/t	Pre-conditioning gas	Pre-conditioning time	collector type	collector addition g/t	flotation gas
bulk rougher - 2 minutes	8.5	-	-	-	SIPX	100	nitrogen
bulk scavenger - 2 minutes	8.5	-	-	-	-	-	nitrogen
zinc rougher - 30 second	10.0	1200	none	5 min	SIPX	50	air
zinc rougher - 1 minute	10.0	-	-	-	-	-	air
zinc rougher - 2 minutes A	10.0	-	-	-	-	-	air
zinc rougher - 2 minutes B	10.0	-	-	-	-	-	air
zinc scavenger - 30 seconds	10.0	-	-	-	SIPX	30	air
zinc scavenger - 1 minute	10.0	-	-	-	-	-	air

GRINDING CONDITIONS:

30 minutes. mild steel charge

1200 g/t zinc sulphate

10-206 Bulk Cu,Pb,pyrite flotation in nitrogen, single addition of collector, zinc flotation in nitrogen.

sample reference	SOLIDS MASS BALANCE sample weight	mass pull sample	mass pull total	COPPER MASS BALANCE copper assay	copper units	copper recovery stage	copper recovery total	LEAD MASS BALANCE lead assay	lead units	lead recovery stage	lead recovery total	ZINC MASS BALANCE zinc assay	zinc units	zinc recovery stage	zinc recovery total	IRON MASS BALANCE iron assay	iron units	iron recovery stage	iron recovery total
zinc rougher - time 30 seconds	24.64	2.50%	2.50%	0.33	0.008	2.64%	2.64%	7.50	0.188	6.34%	6.34%	6.86	0.172	2.39%	2.39%	31.50	0.709	2.78%	2.78%
zinc rougher - time 1 minute	22.16	2.25%	4.76%	0.35	0.008	2.52%	5.15%	5.60	0.126	4.26%	10.60%	7.60	0.171	2.38%	4.76%	32.00	0.721	2.54%	5.32%
zinc scavenger - time 1 minute (I)	27.72	2.82%	7.57%	0.37	0.010	3.33%	8.48%	4.24	0.119	4.03%	14.63%	9.27	0.261	3.63%	8.39%	29.10	0.820	2.89%	8.21%
zinc scavenger - time 1 minute (II)	18.39	1.87%	9.44%	0.40	0.007	2.39%	10.86%	3.94	0.074	2.49%	17.11%	10.80	0.202	2.80%	11.19%	27.40	0.512	1.81%	10.02%
zinc scavenger - time 1 minute (III)	18.68	1.90%	11.34%	0.41	0.008	2.48%	13.35%	3.78	0.072	2.42%	19.54%	13.80	0.262	3.64%	14.83%	26.10	0.496	1.75%	11.77%
zinc scavenger - time 1 minute (IV)	24.31	2.47%	13.81%	0.41	0.010	3.23%	16.58%	3.48	0.086	2.90%	22.44%	11.90	0.294	4.09%	18.91%	25.00	0.610	2.18%	13.95%
zinc scavenger - time 1 minute (V)	14.81	1.51%	15.32%	0.45	0.007	2.16%	18.74%	3.82	0.058	1.94%	24.38%	17.00	0.256	3.55%	22.47%	23.30	0.351	1.24%	15.18%
zinc scavenger - time 1 minute (VI)	22.43	2.28%	17.60%	0.45	0.010	3.27%	22.01%	3.52	0.080	2.71%	27.09%	15.30	0.349	4.84%	27.31%	23.90	0.545	1.92%	17.10%
zinc scavenger - time 1 minute (VII)	31.67	3.22%	20.82%	0.46	0.015	4.72%	26.74%	4.14	0.133	4.50%	31.59%	17.50	0.563	7.82%	35.13%	26.80	0.863	3.04%	20.15%
	779.00	79.18%	100.00%	0.29	0.230	73.26%	100.00%	2.56	2.027	68.41%	100.00%	5.90	4.6[illegible]	64.87%	100.00%	28.60	22.696	79.85%	100.00%
reconstituted feed	983.81				0.313	100.00%			2.963	100.00%			7.207	100.00%			28.360	100.00%	

10-207 Copper activation and zinc flotation in nitrogen only.

F L O T A T I O N   C O N D I T I O N S

sample reference	pH	activator added g/t	Pre-conditioning gas	Pre-conditioning time	collector type	collector addition g/t	flotation gas
zinc rougher - 30 seconds	10.0	1200	nitrogen	5 min	SIPX	50	nitrogen
zinc rougher - 1 minute	10.0	-	-	-	-	-	nitrogen
zinc scavenger - 1 minute I	10.0	-	-	-	SIPX	20	nitrogen
zinc scavenger - 1 minute II	10.0	-	-	-	SIPX	20	nitrogen
zinc scavenger - 1 minute III	10.0	-	-	-	SIPX	20	nitrogen
zinc scavenger - 1 minute IV	10.0	-	-	-	SIPX	20	nitrogen
zinc scavenger - 1 minute V	10.0	-	-	-	SIPX	20	nitrogen
zinc scavenger - 1 minute VI	10.0	-	-	-	SIPX	20	nitrogen
zinc scavenger - 1 minute VII	10.0	-	-	-	SIPX	50	nitrogen

GRINDING CONDITIONS:

30 minutes, stainless steel charge

1200 g/t zinc sulphate

10-207 - Copper activation and zinc flotation in nitrogen only.

sample reference	SOLIDS MASS BALANCE sample weight	mass pull sample	mass pull total	COPPER MASS BALANCE copper assay	copper units	copper recovery stage	copper recovery total	LEAD MASS BALANCE lead assay	lead units	lead recovery stage	lead recovery total	ZINC MASS BALANCE zinc assay	zinc units	zinc recovery stage	zinc recovery total	IRON MASS BALANCE iron assay	iron units	iron recovery stage	iron recovery total
bulk rougher - 2 minutes	53.54	5.22%	5.22%	2.66	0.139	43.35%	43.35%	5.06	0.264	7.39%	7.39%	6.73	0.351	5.10%	5.10%	33.22	1.733	6.12%	6.12%
bulk scavenger - 2 minutes	130.70	12.74%	17.96%	0.53	0.068	21.09%	64.44%	2.90	0.380	10.63%	18.02%	3.93	0.501	7.27%	12.37%	39.10	4.981	17.58%	23.70%
zinc rougher - time 30 seconds	33.22	3.24%	21.19%	0.37	0.012	3.74%	68.18%	7.24	0.234	6.56%	24.58%	30.60	0.991	14.39%	26.75%	16.10	0.521	1.84%	25.53%
zinc rougher - time 1 minute	36.52	3.56%	24.75%	0.34	0.012	3.78%	71.96%	8.98	0.320	8.95%	33.53%	28.40	1.011	14.68%	41.43%	17.90	0.637	2.25%	27.78%
zinc rougher - time 2 minutes A	28.24	2.75%	27.50%	0.29	0.008	2.49%	74.45%	8.48	0.233	6.53%	40.06%	25.10	0.691	10.03%	51.46%	19.90	0.548	1.93%	29.72%
zinc rougher - time 2 minutes B	17.98	1.75%	29.26%	0.27	0.005	1.48%	75.93%	6.78	0.119	3.33%	43.39%	23.30	0.408	5.93%	57.39%	21.10	0.370	1.30%	31.02%
zinc scavenger - time 30 seconds	228.41	22.26%	51.52%	0.14	0.031	9.73%	85.67%	3.66	0.815	22.81%	66.20%	8.99	2.001	29.06%	86.45%	36.00	8.014	28.28%	59.30%
zinc scavenger - time 1 minute	119.55	11.65%	63.17%	0.15	0.017	5.46%	91.13%	2.70	0.315	8.81%	75.00%	5.09	0.593	8.61%	95.06%	39.40	4.591	16.20%	75.51%
zinc scavenger - time 2 minutes A	48.42	4.72%	67.89%	0.15	0.007	2.21%	93.34%	2.32	0.109	3.06%	78.07%	3.20	0.151	2.19%	97.26%	39.90	1.883	6.65%	82.15%
zinc scavenger - time 2 minutes B	21.19	2.07%	69.95%	0.16	0.003	1.03%	94.37%	2.14	0.044	1.24%	79.31%	2.46	0.051	0.74%	97.99%	38.30	0.791	2.79%	84.94%
final tails	308.30	30.05%	100.00%	0.06	0.018	5.63%	100.00%	2.46	0.739	20.69%	100.00%	0.46	0.138	2.01%	100.00%	14.20	4.267	15.06%	100.00%
reconstituted feed	1026.07				0.320	100.00%			3.572	100.00%			6.007	100.00%			20.335	100.00%	

TEST SUMMARY:	sample weight	mass pull sample	mass pull total	copper assay %	recovery stage	recovery total	lead assay %	recovery stage	recovery total	zinc assay %	recovery stage	recovery total	iron assay %	recovery stage	recovery total
bulk flotation	184.24	17.96%	17.96%	1.15	64.44%	64.44%	3.58	18.02%	18.02%	4.74	12.37%	12.37%	37.39	23.70%	23.70%
zinc rougher flotation	115.96	11.30%	29.26%	0.33	11.49%	75.93%	8.02	25.37%	43.39%	27.44	45.02%	57.39%	18.37	7.33%	31.02%
zinc scavenger flotation time 0 1.5 min	347.96	33.91%	63.17%	0.14	15.19%	91.13%	3.33	31.62%	75.00%	7.65	37.67%	95.06%	37.17	44.48%	75.51%
zinc scavenger flotation time 1.5min+	69.61	6.78%	69.95%	0.15	3.24%	94.37%	2.27	4.30%	79.31%	2.97	2.93%	97.99%	39.41	9.44%	84.94%
final flotation tails	308.30	30.05%	100.00%	0.06	5.63%	100.00%	2.46	20.69%	100.00%	0.46	2.01%	100.00%	14.20	15.06%	100.00%

10-208 Bulk Cu,Pb, pyrite flotation in nitrogen, zinc flotation

F L O T A T I O N   C O N D I T I O N S

sample reference	pH	activator added g/t	Pre-conditioning gas	Pre-conditioning time	collector type	collector addition g/t	flotation gas
bulk rougher - 2 minutes A	8.5	-	nitrogen	20 min	SIPX	50	nitrogen
bulk rougher - 2 minutes B	8.5	-	-	-	SIPX	30	nitrogen
zinc rougher - 30 second	10.0	1200	none	5 min	SIPX	50	nitrogen
zinc rougher - 1 minute	10.0	-	-	-	-	-	nitrogen
zinc rougher - 2 minutes A	10.0	-	-	-	-	-	nitrogen
zinc rougher - 2 minutes B	10.0	-	-	-	-	-	nitrogen
zinc scavenger - 30 seconds	10.0	-	-	-	SIPX	30	nitrogen
zinc scavenger - 1 minute	10.0	-	-	-	-	-	nitrogen
zinc scavenger - 2 minutes A	10.0	-	-	-	-	-	nitrogen
zinc scavenger - 2 minutes B	10.0	-	-	-	-	-	nitrogen

GRINDING CONDITIONS:

30 minutes, stainless steel charge

1200 g/t zinc sulphate

10-208 Bulk Cu,Pb, pyrite flotation in nitrogen & zinc flotation

sample reference	SOLIDS MASS BALANCE: sample weight	mass pull: sample	mass pull: total	COPPER MASS BALANCE: copper assay (%)	copper units	copper recovery: stage	copper recovery: total	LEAD MASS BALANCE: lead assay (%)	lead units	lead recovery: stage	lead recovery: total	ZINC MASS BALANCE: zinc assay (%)	zinc units	zinc recovery: stage	zinc recovery: total	IRON MASS BALANCE: iron assay (%)	iron units	iron recovery: stage	iron recovery: total
bulk rougher - 2 minutes	386.38	39.73%	39.73%	0.60	0.230	71.13%	71.13%	5.24	2.082	67.89%	67.89%	4.52	1.796	24.38%	24.38%	40.10	15.933	54.89%	54.89%
bulk scavenger - 2 minutes	41.90	4.31%	44.04%	0.69	0.030	8.87%	80.00%	5.82	0.251	8.18%	76.07%	8.01	0.345	4.68%	29.06%	35.30	1.521	5.24%	60.13%
zinc rougher - time 30 seconds	62.59	6.44%	50.48%	0.23	0.015	4.42%	84.42%	2.06	0.133	4.32%	80.39%	45.20	2.909	39.49%	68.56%	12.70	0.817	2.82%	62.94%
zinc rougher - time 1 minute	33.45	3.46%	53.92%	0.25	0.009	2.57%	86.98%	2.44	0.084	2.74%	83.13%	35.20	1.211	16.44%	84.99%	16.90	0.550	1.90%	64.84%
zinc rougher - time 2 minutes A	24.92	2.56%	56.48%	0.24	0.006	1.84%	88.82%	2.40	0.062	2.01%	85.13%	21.10	0.541	7.34%	92.33%	25.60	0.656	2.26%	67.10%
zinc rougher - time 2 minutes B	14.75	1.52%	58.00%	0.22	0.003	1.00%	89.81%	1.76	0.027	0.87%	86.00%	12.50	0.190	2.57%	94.91%	30.60	0.464	1.60%	68.70%
zinc scavenger - time 30 seconds	19.89	2.05%	60.04%	0.17	0.003	1.04%	90.85%	1.94	0.040	1.29%	87.30%	4.60	0.094	1.28%	96.18%	37.20	0.761	2.62%	71.32%
zinc scavenger - time 1 minute	29.14	3.00%	63.04%	0.16	0.005	1.43%	92.28%	1.90	0.057	1.86%	89.15%	2.97	0.089	1.21%	97.39%	37.30	1.118	3.85%	75.17%
final tails	359.43	36.96%	100.00%	0.07	0.026	7.72%	100.00%	0.90	0.333	10.85%	100.00%	0.52	0.192	2.61%	100.00%	19.50	7.207	24.83%	100.00%
reconstituted feed	972.45				0.335	100.00%			3.067	100.00%			7.367	100.00%			29.028	100.00%	

TEST SUMMARY:	sample weight	mass pull: sample	mass pull: total	copper assay %	recovery: stage	recovery: total	lead assay %	recovery: stage	recovery: total	zinc assay %	recovery: stage	recovery: total	iron assay %	recovery: stage	recovery: total
bulk flotation	428.20	44.04%	44.04%	0.61	80.00%	80.00%	5.30	76.07%	76.07%	4.86	29.06%	29.06%	39.63	60.13%	60.13%
zinc rougher flotation	135.71	13.96%	58.00%	0.24	9.81%	89.81%	2.18	9.94%	86.00%	34.76	65.84%	94.91%	17.83	8.57%	68.70%
zinc scavenger flotation time 0-1.5 min	49.03	5.04%	63.04%	0.16	7.47%	92.28%	1.92	3.15%	89.15%	3.63	2.48%	97.39%	37.26	6.47%	75.17%
final flotation tails	359.43	36.96%	100.00%	0.07	7.72%	100.00%	0.90	10.85%	100.00%	0.52	2.61%	100.00%	19.50	24.83%	100.00%

10-209 Nitrogen conditioning, then Cu,Pb,pyrite flotation in air and zinc flotation in air.

FLOTATION CONDITIONS

sample reference	pH	activator added g/t	Pre-conditioning gas	Pre-conditioning time	collector type	collector addition g/t	flotation gas
bulk rougher - 2 minutes	8.5	-	nitrogen	15 sec	SIPX	50	air
bulk scavenger - 2 minutes	8.5	-	-	-	SIPX	30	air
zinc rougher - 30 second	10.0	1200	none	5 min	SIPX	50	air
zinc rougher - 1 minute	10.0	-	-	-	-	-	air
zinc rougher - 2 minutes A	10.0	-	-	-	-	-	air
zinc rougher - 2 minutes B	10.0	-	-	-	-	-	air
zinc scavenger - 30 seconds	10.0	-	-	-	SIPX	30	air
zinc scavenger - 1 minute	10.0	-	-	-	-	-	air

GRINDING CONDITIONS:

30 minutes, mild steel charge

1200 g/t zinc sulphate

10-209 Nitrogen conditioning, then Cu,Pb,pyrite flotation in air and zinc flotation in air.

sample reference	sample weight (grams)	mass pull sample	mass pull total	copper assay (%)	copper units	copper recovery stage	copper recovery total	lead assay (%)	lead units	lead recovery stage	lead recovery total	zinc assay (%)	zinc units	zinc recovery stage	zinc recovery total	iron assay (%)	iron units	iron recovery stage	iron recovery total
	SOLIDS MASS BALANCE			COPPER MASS BALANCE				LEAD MASS BALANCE				ZINC MASS BALANCE				IRON MASS BALANCE			
bulk rougher - 2 minutes	417.70	43.02%	43.02%	0.57	0.245	75.76%	75.76%	5.36	2.306	68.62%	68.62%	3.73	1.605	21.49%	21.49%	38.90	16.736	59.06%	59.06%
bulk scavenger - 2 minutes	138.70	14.29%	57.31%	0.21	0.030	9.27%	85.03%	3.88	0.554	16.49%	85.11%	9.47	1.353	18.11%	39.60%	34.50	4.929	17.39%	76.45%
zinc rougher - time 30 seconds	72.68	7.49%	64.80%	0.20	0.015	4.63%	89.66%	1.28	0.096	2.85%	87.96%	44.60	3.339	44.70%	84.30%	12.20	0.913	3.22%	79.67%
zinc rougher - time 1 minute	27.48	2.83%	67.63%	0.27	0.008	2.36%	92.02%	2.16	0.061	1.82%	89.78%	27.00	0.764	10.23%	94.54%	21.90	0.620	2.19%	81.86%
zinc rougher - time 2 minutes A	22.42	2.31%	69.94%	0.26	0.006	1.85%	93.87%	2.62	0.061	1.80%	91.58%	8.77	0.203	2.71%	97.25%	31.60	0.730	2.58%	84.44%
zinc rougher - time 2 minutes B	12.94	1.33%	71.27%	0.21	0.003	0.86%	94.74%	2.40	0.032	0.95%	92.53%	3.21	0.043	0.57%	97.82%	31.90	0.425	1.50%	85.94%
zinc scavenger - time 30 seconds	14.11	1.45%	72.72%	0.15	0.002	0.67%	95.41%	1.82	0.026	0.79%	93.32%	2.03	0.030	0.40%	98.22%	35.10	0.510	1.80%	87.74%
zinc scavenger - time 1 minute	10.75	1.11%	73.83%	0.16	0.002	0.55%	95.96%	1.84	0.020	0.61%	93.93%	1.16	0.013	0.17%	98.39%	32.60	0.361	1.27%	89.01%
final tails	254.08	26.17%	100.00%	0.05	0.013	4.04%	100.00%	0.78	0.204	6.07%	100.00%	0.46	0.120	1.61%	100.00%	11.90	3.114	10.99%	100.00%
reconstituted feed	970.86				0.324	100.00%			3.361	100.00%			7.469	100.00%			28.338	100.00%	

TEST SUMMARY:	sample weight	mass pull sample	mass pull total	copper assay %	recovery stage	recovery total	lead assay %	recovery stage	recovery total	zinc assay %	recovery stage	recovery total	iron assay %	recovery stage	recovery total
bulk flotation	556.40	57.31%	57.31%	0.48	85.03%	85.03%	4.99	85.11%	85.11%	5.16	39.60%	39.60%	37.80	76.45%	76.45%
zinc rougher flotation	135.52	13.96%	71.27%	0.23	9.71%	94.74%	1.79	7.42%	92.53%	31.15	58.22%	97.82%	19.26	9.49%	85.94%
zinc scavenger flotation time 0 1.5 min	24.86	2.56%	73.83%	0.15	1.22%	95.96%	1.83	1.39%	93.93%	1.65	0.57%	98.39%	34.02	3.07%	89.01%
final flotation tails	254.08	26.17%	100.00%	0.05	4.04%	100.00%	0.78	6.07%	100.00%	0.46	1.61%	100.00%	11.90	10.99%	100.00%

10-210 Nitrogen conditioning, then Cu,Pb,pyrite flotation in air, followed by nitrogen conditioning and zinc flotation in air.

FLOTATION CONDITIONS

sample reference	pH	activator added g/t	Pre-conditioning gas	Pre-conditioning time	collector type	collector addition g/t	flotation gas
bulk rougher - 2 minutes	8.5	-	nitrogen	3 min	SIPX	50	air
bulk scavenger - 2 minutes	8.5	-	nitrogen	3 min	SIPX	30	air
zinc rougher - 30 second	10.0	1200	none	5 min	SIPX*	50	air
zinc rougher - 1 minute	10.0	-	-	-	-	-	air
zinc rougher - 2 minutes A	10.0	-	-	-	-	-	air
zinc rougher - 2 minutes B	10.0	-	-	-	-	-	air
zinc scavenger - 30 seconds	10.0	-	-	-	SIPX*	30	air
zinc scavenger - 1 minute	10.0	-	-	-	-	-	air

GRINDING CONDITIONS:

30 minutes, mild steel charge

1200 g/t zinc sulphate

NOTE:

Nitrogen added during xanthate collection period in zinc flotation stages. (see *)

10-210 Nitrogen conditioning, then Cu,Pb,pyrite flotation in air, followed by nitrogen conditioning and zinc flotation in air.

	SOLIDS MASS BALANCE			COPPER MASS BALANCE				LEAD MASS BALANCE				ZINC MASS BALANCE				IRON MASS BALANCE			
sample reference	sample weight (grams)	mass pull sample	mass pull total	copper assay (%)	copper units	copper recovery stage	copper recovery total	lead assay (%)	lead units	lead recovery stage	lead recovery total	zinc assay (%)	zinc units	zinc recovery stage	zinc recovery total	iron assay (%)	iron units	iron recovery stage	iron recovery total
bulk rougher - 2 minutes (A)	160.55	16.21%	16.21%	1.46	0.237	72.26%	72.26%	13.50	2.188	67.11%	67.11%	9.05	1.467	19.24%	19.24%	30.10	4.879	17.22%	17.22%
bulk rougher - 2 minutes (B)	69.07	6.97%	23.18%	0.29	0.020	6.17%	78.43%	4.14	0.289	8.85%	75.97%	10.10	0.704	9.24%	28.48%	33.70	2.350	8.30%	25.52%
bulk scavenger - 2 minutes (A)	81.21	8.20%	31.38%	0.13	0.011	3.25%	81.69%	2.06	0.169	5.18%	81.15%	7.19	0.590	7.73%	36.21%	37.10	3.042	10.74%	36.25%
bulk scavenger - 2 minutes (B)	15.05	1.52%	32.90%	0.13	0.002	0.60%	82.29%	2.34	0.036	1.09%	82.24%	11.50	0.175	2.29%	38.50%	29.30	0.445	1.57%	37.83%
zinc rougher - time 30 seconds	50.75	5.12%	38.07%	0.17	0.009	2.66%	84.95%	0.90	0.046	1.41%	83.65%	46.30	2.373	31.11%	69.62%	15.30	0.784	2.77%	40.59%
zinc rougher - time 1 minute	42.01	4.24%	42.27%	0.16	0.007	2.07%	87.02%	1.28	0.054	1.66%	85.31%	31.20	1.323	17.36%	86.97%	20.00	0.848	2.99%	43.59%
zinc rougher - time 2 minutes A	38.72	3.91%	46.18%	0.15	0.006	1.79%	88.81%	1.62	0.063	1.94%	87.26%	17.40	0.680	8.92%	95.89%	29.20	1.142	4.03%	47.62%
zinc rougher - time 2 minutes B	22.10	2.23%	48.41%	0.15	0.003	1.02%	89.84%	1.74	0.039	1.19%	88.45%	4.62	0.103	1.35%	97.25%	36.30	0.810	2.86%	50.48%
zinc scavenger - time 30 seconds	40.67	4.11%	52.52%	0.09	0.004	1.13%	90.96%	0.90	0.037	1.13%	89.58%	1.08	0.044	0.58%	97.83%	43.10	1.770	6.25%	56.72%
zinc scavenger - time 1 minute	36.56	3.69%	56.21%	0.09	0.003	1.01%	91.98%	0.90	0.033	1.02%	90.60%	0.81	0.030	0.39%	98.22%	42.70	1.576	5.56%	62.29%
final tails	433.70	43.79%	100.00%	0.06	0.026	8.02%	100.00%	0.70	0.307	9.40%	100.00%	0.31	0.136	1.78%	100.00%	24.40	10.685	37.71%	100.00%
reconstituted feed	990.39				0.328	100.00%			3.261	100.00%			7.625	100.00%			28.332	100.00%	

TEST SUMMARY:	sample weight	mass pull sample	mass pull total	copper assay %	recovery stage	recovery total	lead assay %	recovery stage	recovery total	zinc assay %	recovery stage	recovery total	iron assay %	recovery stage	recovery total
bulk flotation	229.62	23.18%	23.18%	1.11	78.43%	78.43%	10.68	75.97%	75.97%	9.37	28.48%	28.48%	31.18	25.52%	25.52%
pyrite flotation	96.26	9.72%	32.90%	0.13	3.86%	82.29%	2.10	6.27%	82.24%	7.86	10.02%	38.50%	35.88	12.31%	37.83%
zinc rougher flotation	153.58	15.51%	48.41%	0.16	7.54%	89.84%	1.31	6.21%	88.45%	28.89	58.74%	97.25%	23.11	12.65%	50.48%
zinc scavenger flotation time 0 1.5 min	77.23	7.80%	56.21%	0.09	2.14%	91.98%	0.90	2.15%	90.60%	0.95	0.97%	98.22%	42.91	11.81%	62.29%
final flotation tails	433.70	43.79%	100.00%	0.06	8.02%	100.00%	0.70	9.40%	100.00%	0.31	1.78%	100.00%	24.40	37.71%	100.00%

10-211 Bulk copper, lead, pyrite flotation in nitrogen then zinc flotation in air

F L O T A T I O N   C O N D I T I O N S

sample reference	pH	activator added g/t	Pre-conditioning gas	Pre-conditioning time	collector type	collector addition g/t	flotation gas
bulk rougher - 2 minutes A	8.5	-		10 min	SIPX	50	
bulk rougher - 2 minutes B	8.5	-	-	-	SIPX	30	
bulk scavenger - 2 minutes A	8.5	-	-	-	SIPX*	50	
bulk scavenger - 2 minutes B	8.5	-	-	-	-	-	
zinc rougher - 30 second	10.0	1200	none	5 min	SIPX*	50	air
zinc rougher - 1 minute	10.0	-	-	-	-	-	air
zinc rougher - 2 minutes A	10.0	-	-	-	-	-	air
zinc rougher - 2 minutes B	10.0	-	-	-	-	-	air
zinc scavenger - 30 seconds	10.0	-	-	-	SIPX*	30	air
zinc scavenger - 1 minute	10.0	-	-	-	-	-	air

GRINDING CONDITIONS:

30 minutes, mild steel charge

1200 g t zinc sulphate

NOTE:

Nitrogen added during xanthate conditioning period (see *)

10-211 Bulk copper,lead,pyrite flotation in nitrogen then zinc flotation in air

sample reference	SOLIDS MASS BALANCE sample weight (grams)	mass pull sample	mass pull total	COPPER MASS BALANCE copper assay (%)	copper units	copper recovery stage	copper recovery total	LEAD MASS BALANCE lead assay (%)	lead units	lead recovery stage	lead recovery total	ZINC MASS BALANCE zinc assay (%)	zinc units	zinc recovery stage	zinc recovery total	IRON MASS BALANCE iron assay (%)	iron units	iron recovery stage	iron recovery total
bulk rougher - 2 minutes	195.00	18.66%	18.66%	1.12	0.209	65.72%	65.72%	10.40	1.940	50.53%	50.53%	7.2[illegible]	1.345	15.04%	15.04%	30.10	5.616	23.60%	23.60%
bulk scavenger - 2 minutes	115.28	11.03%	29.69%	0.32	0.035	11.10%	76.82%	10.00	1.103	28.73%	79.26%	8.52	0.940	10.51%	25.54%	32.50	3.584	15.06%	38.66%
pyrite conc - 2n scavenger 1	10.53	1.01%	30.69%	0.36	0.004	1.14%	77.96%	3.43	0.035	0.90%	80.16%	37.70	0.380	4.25%	29.79%	16.90	0.169	0.71%	39.37%
pyrite conc - 2n scavenger 2	6.58	0.63%	31.32%	0.29	0.002	0.57%	78.54%	3.02	0.019	0.50%	80.65%	36.00	0.227	2.53%	32.32%	17.50	0.110	0.46%	39.83%
pyrite final conc (2n scav tails)	328.59	31.44%	62.76%	0.11	0.035	10.88%	89.42%	1.67	0.525	13.67%	94.33%	6.90	2.169	24.25%	56.58%	36.50	11.475	48.21%	88.05%
pyrite rghr concentrate	345.70	33.07%		0.12		12.59%		1.75		15.07%		8.39		31.03%		35.54		49.39%	
zinc rougher - time 30 seconds	45.49	4.35%	67.11%	0.17	0.007	2.33%	91.74%	0.75	0.033	0.85%	95.18%	50.40	2.193	24.52%	81.10%	8.05	0.350	1.47%	89.52%
zinc rougher - time 1 minute	24.02	2.30%	69.41%	0.19	0.004	1.37%	93.12%	0.94	0.022	0.56%	95.74%	40.30	0.926	10.35%	91.45%	10.40	0.239	1.00%	90.52%
zinc rougher - time 2 minutes	15.73	1.50%	70.91%	0.23	0.003	1.09%	94.20%	1.27	0.019	0.50%	96.24%	28.30	0.426	4.76%	96.21%	13.70	0.206	0.87%	91.39%
zinc scavenger - time 30 seconds	13.11	1.25%	72.17%	0.22	0.003	0.87%	95.07%	1.47	0.018	0.48%	96.72%	12.30	0.154	1.72%	97.94%	16.80	0.211	0.89%	92.27%
zinc scavenger - time 1 minute	13.06	1.25%	73.42%	0.19	0.002	0.75%	95.82%	1.36	0.017	0.44%	97.16%	5.60	0.070	0.78%	98.72%	15.90	0.199	0.83%	93.11%
final tails	277.84	26.58%	100.00%	0.05	0.013	4.18%	100.00%	0.41	0.109	2.84%	100.00%	0.43	0.114	1.28%	100.00%	6.17	1.640	6.89%	100.00%
reconstituted feed	1045.23				0.318	100.00%			3.839	100.00%			8.944	100.00%			23.799	100.00%	

TEST SUMMARY:	sample weight	mass pull sample	mass pull total	copper assay %	copper recovery stage	copper recovery total	lead assay %	lead recovery stage	lead recovery total	zinc assay %	zinc recovery stage	zinc recovery total	iron assay %	iron recovery stage	iron recovery total
bulk flotation	310.28	29.69%	29.69%	0.82	76.82%	76.82%	10.25	79.26%	79.26%	7.70	25.54%	25.54%	30.99	38.66%	38.66%
pyrite flotation-rougher concentrate	345.70	33.07%	62.76%	0.12	12.59%	89.42%	1.75	15.07%	94.33%	8.39	31.03%	56.58%	35.54	49.39%	88.05%
zinc rougher flotation	85.24	8.16%	70.91%	0.19	4.79%	94.20%	0.90	1.91%	96.24%	43.48	39.64%	96.21%	9.75	3.34%	91.39%
zinc scavenger flotation time 0-1.5 min	26.17	2.50%	73.42%	0.21	1.61%	95.82%	1.42	0.92%	97.16%	8.96	2.51%	98.72%	16.35	1.72%	93.11%
final flotation tails	277.84	26.58%	100.00%	0.05	4.18%	100.00%	0.41	2.84%	100.00%	0.43	1.28%	100.00%	6.17	6.89%	100.00%

10-212 Bulk copper,lead flotation in air, then pyrite flotation in nitrogen with zinc reverse cleaning, finally zinc flotation in air.

FLOTATION CONDITIONS

sample reference	pH	activator added g/t	Pre-conditioning gas	Pre-conditioning time	collector type	collector addition g/t	flotation gas
bulk rougher - time 2 minutes	8.5	-	air	10 min	SIPX	50	air
bulk scavenger - time 2 minutes	8.5	-	-	-	SIPX	30	air
pyrite rougher - time 2 minutes A	8.5	-	nitrogen	2 min	SIPX	5	nitrogen
pyrite rougher - time 2 minutes B	8.5	-	nitrogen	2 min	SIPX	5	nitrogen
pyrite rougher - time 2 minutes C	8.5	-	nitrogen	2 min	SIPX	5	nitrogen
pyrite rougher - time 2 minutes D	8.5	-	nitrogen	2 min	SIPX	5	nitrogen
zinc rougher - time 30 seconds	10.0	1200	-	5 min	SIPX	50	air
zinc rougher - time 1 minute	10.0	-	-	-	-	-	air
zinc rougher - time 2 minutes	10.0	-	-	-	-	-	air
zinc scavenger - time 0.5 minutes	10.0	-	-	-	SIPX	30	air
zinc scavenger - time 1 minute	10.0	-	-	-	-	-	air
zinc reverse rougher - 1 minute	10.0	200	none	5 min	SIPX	50	air
zinc reverse scavenger - 1 minute	10.0	-	-	-	-	-	air

GRINDING CONDITIONS:

30 minutes, mild steel charge

Zinc Sulphate, 1200 g/t

10-212 Bulk copper,lead flotation in air, then pyrite flotation in nitrogen with zinc reverse cleaning, finally zinc flotation in air.

sample reference	SOLIDS MASS BALANCE: sample weight (grams)	mass pull: sample	mass pull: total	COPPER MASS BALANCE: copper assay (%)	copper units	copper recovery: stage	copper recovery: total	LEAD MASS BALANCE: lead assay (%)	lead units	lead recovery: stage	lead recovery: total
bulk rougher - 2 minutes	130.07	12.08%	12.08%	1.70	0.205	64.96%	64.96%	16.80	2.030	62.20%	62.20%
bulk scavenger - 2 minutes	72.59	6.74%	18.83%	0.39	0.026	8.32%	73.28%	5.33	0.359	11.01%	73.21%
pyrite conc - Zn scavenger 1	15.52	1.44%	20.27%	0.21	0.003	0.96%	74.24%	1.61	0.023	0.71%	73.92%
pyrite conc - Zn scavenger 2	13.59	1.26%	21.53%	0.22	0.003	0.88%	75.12%	1.96	0.025	0.76%	74.68%
pyrite final conc (Zn scav tails)	408.10	37.92%	59.45%	0.11	0.042	13.19%	88.31%	1.48	0.561	17.19%	91.87%
pyrite rghr concentrate	437.21	40.62%		0.12		15.02%		1.50		18.66%	
zinc rougher - time 30 seconds	39.32	3.65%	63.10%	0.16	0.006	1.85%	90.15%	0.83	0.030	0.93%	92.80%
zinc rougher - time 1 minute	42.47	3.95%	67.05%	0.19	0.007	2.37%	92.52%	1.02	0.040	1.23%	94.04%
zinc rougher - time 2 minutes	22.56	2.10%	69.15%	0.19	0.004	1.26%	93.78%	1.44	0.030	0.92%	94.96%
zinc scavenger - time 30 seconds	17.67	1.64%	70.79%	0.22	0.004	1.14%	94.93%	1.45	0.024	0.73%	95.69%
zinc scavenger - time 1 minute	12.92	1.20%	71.99%	0.17	0.002	0.65%	95.57%	1.45	0.017	0.53%	96.22%
zinc scavenger - time 2 minutes	0.00	0.00%	71.99%	0.18	0.000	0.00%	95.57%	0.00	0.000	0.00%	96.22%
final tails	301.50	28.01%	100.00%	0.05	0.014	4.43%	100.00%	0.44	0.123	3.78%	100.00%
reconstituted feed	1076.31				0.316	100.00%			3.264	100.00%	

sample reference	ZINC MASS BALANCE: zinc assay (%)	zinc units	zinc recovery: stage	zinc recovery: total	IRON MASS BALANCE: iron assay (%)	iron units	iron recovery: stage	iron recovery: total
bulk rougher - 2 minutes	8.24	0.996	11.04%	11.04%	25.40	3.070	12.54%	12.54%
bulk scavenger - 2 minutes	11.40	0.769	8.53%	19.57%	29.60	1.996	8.15%	20.69%
pyrite conc - Zn scavenger 1	44.20	0.637	7.07%	26.64%	14.50	0.209	0.85%	21.54%
pyrite conc - Zn scavenger 2	33.50	0.423	4.69%	31.33%	20.50	0.259	1.06%	22.60%
pyrite final conc (Zn scav tails)	4.86	1.843	20.44%	51.76%	40.50	15.356	62.72%	85.32%
pyrite rghr concentrate	7.15		32.19%		38.96		64.63%	
zinc rougher - time 30 seconds	50.10	1.830	20.30%	72.06%	9.12	0.333	1.36%	86.68%
zinc rougher - time 1 minute	41.70	1.645	18.25%	90.31%	12.40	0.489	2.00%	88.68%
zinc rougher - time 2 minutes	26.50	0.555	6.16%	96.47%	16.60	0.348	1.42%	90.10%
zinc scavenger - time 30 seconds	8.06	0.132	1.47%	97.93%	17.00	0.292	1.19%	91.29%
zinc scavenger - time 1 minute	4.56	0.055	0.61%	98.54%	16.60	0.199	0.81%	92.11%
zinc scavenger - time 2 minutes	0.00	0.000	0.00%	98.54%	0.00	0.000	0.00%	91.29%
final tails	0.47	0.132	1.46%	100.00%	6.90	1.933	7.89%	99.19%
reconstituted feed		9.018	100.00%			24.485	100.00%	

TEST SUMMARY:

	sample weight	mass pull: sample	mass pull: total	copper assay %	copper recovery: stage	copper recovery: total	lead assay %	lead recovery: stage	lead recovery: total
bulk flotation	202.66	18.83%	18.83%	1.23	73.28%	73.28%	12.69	73.21%	73.21%
pyrite flotation	437.21	40.62%	59.45%	0.12	15.02%	88.31%	1.50	18.66%	91.87%
zinc rougher flotation	104.35	9.70%	69.15%	0.18	5.48%	93.78%	1.04	3.09%	94.96%
zinc scavenger flotation time	30.59	2.84%	71.99%	0.20	1.79%	95.57%	1.45	1.26%	96.22%
final flotation tails	301.50	28.01%	100.00%	0.05	4.43%	100.00%	0.44	3.78%	100.00%

	zinc assay %	zinc recovery: stage	zinc recovery: total	iron assay %	iron recovery: stage	iron recovery: total
bulk flotation	9.37	19.57%	19.57%	26.90	20.69%	29.69%
pyrite flotation	7.15	32.19%	51.76%	38.96	64.63%	85.32%
zinc rougher flotation	41.58	44.70%	96.47%	12.07	4.78%	90.10%
zinc scavenger flotation time	6.58	2.07%	98.54%	17.29	2.01%	92.11%
final flotation tails	0.47	1.46%	100.00%	6.90	7.89%	100.00%

10-213 Bulk copper, lead flotation in air, then pyrite flotation in nitrogen with zinc reverse cleaning, finally zinc flotation in air. (repeat of test 10-212)

F L O T A T I O N   C O N D I T I O N S

sample reference	pH	activator added g/t	Pre-conditioning gas	Pre-conditioning time	collector type	collector addition g/t	flotation gas
bulk rougher - time 2 minutes	8.5	-	air	10 min	SIPX	50	air
bulk scavenger - time 2 minutes	8.5	-	-	-	SIPX	30	air
pyrite rougher - time 2 minutes A	8.5	-	nitrogen	2 min	SIPX	5	nitrogen
pyrite rougher - time 2 minutes B	8.5	-	nitrogen	2 min	SIPX	5	nitrogen
pyrite rougher - time 2 minutes C	8.5	-	nitrogen	2 min	SIPX	5	nitrogen
pyrite rougher - time 2 minutes D	8.5	-	nitrogen	2 min	SIPX	5	nitrogen
pyrite rougher - time 2 minutes E	8.5	-	nitrogen	2 min	SIPX	5	nitrogen
pyrite rougher - time 2 minutes F	8.5	-	nitrogen	2 min	SIPX	5	nitrogen
pyrite rougher - time 2 minutes G	8.5	-	nitrogen	2 min	SIPX	5	nitrogen
pyrite rougher - time 2 minutes H	8.5	-	nitrogen	2 min	SIPX	5	nitrogen
zinc rougher - time 30 seconds	10.0	1200	-	5 min	SIPX	50	air
zinc rougher - time 1 minute	10.0	-	-	-	-	-	air
zinc rougher - time 2 minutes	10.0	-	-	-	-	-	air
zinc scavenger - time 0.5 minutes	10.0	-	-	-	SIPX	30	air
zinc scavenger - time 1 minute	10.0	-	-	-	-	-	air
zinc reverse rougher - 1 minute	10.0	200	none	5 min	SIPX	8	air
zinc reverse scavenger - 1 minute	10.0	-	-	-	-	-	air

GRINDING CONDITIONS:

30 minutes, mild steel charge

Zinc Sulphate, 1200 g/t

10-213 Bulk copper,lead flotation in air, then pyrite flotation in nitrogen with zinc reverse cleaning, finally zinc flotation in air (repeat of test 10-212)

sample reference	SOLIDS MASS BALANCE: sample weight (grams)	mass pull sample	mass pull total	COPPER MASS BALANCE: copper assay	copper units	copper recovery stage	copper recovery total	LEAD MASS BALANCE: lead assay	lead units	lead recovery stage	lead recovery total	ZINC MASS BALANCE: zinc assay	zinc units	zinc recovery stage	zinc recovery total	IRON MASS BALANCE: iron assay	iron units	iron recovery stage	iron recovery total
bulk rougher - time 1.5 minutes	20.30	2.50%	2.50%	1.43	0.036	9.67%	9.67%	12.50	0.313	4.62%	4.62%	7.13	0.178	1.91%	1.91%	27.50	0.688	2.83%	2.83%
bulk scavenger - time 1.5 minutes	68.50	8.44%	10.94%	1.93	0.163	44.06%	53.73%	43.40	3.663	54.09%	58.71%	9.89	0.835	8.93%	10.84%	21.60	1.823	7.49%	[illegible]
pyrite rougher - time 2 minutes A	58.60	7.22%	18.16%	0.53	0.038	10.35%	64.08%	11.80	0.852	12.58%	71.29%	11.30	0.816	8.73%	19.57%	30.80	2.224	9.14%	19.46%
pyrite rougher - time 2 minutes B	48.00	5.91%	24.08%	0.30	0.018	4.80%	68.88%	6.11	0.361	5.34%	76.63%	9.44	0.558	5.97%	25.54%	34.60	2.047	8.41%	27.87%
pyrite rougher - time 2 minutes C	116.70	14.38%	38.46%	0.16	0.023	6.22%	75.10%	2.88	0.414	6.12%	82.74%	7.05	1.014	10.84%	36.38%	32.70	4.702	19.33%	47.20%
pyrite rougher - time 2 minutes D	83.00	10.23%	48.69%	0.14	0.014	3.87%	78.97%	2.22	0.227	3.35%	86.10%	5.80	0.593	6.35%	42.73%	38.80	3.968	16.31%	63.51%
zinc rougher - time 30 seconds	29.60	3.65%	52.37%	0.17	0.006	1.68%	80.65%	2.02	0.074	1.09%	87.18%	45.90	1.674	17.91%	60.64%	9.89	0.761	1.49%	65.00%
zinc rougher - time 1 minute	32.70	4.03%	56.76%	0.21	0.008	2.29%	82.94%	2.36	0.095	1.40%	88.59%	44.29	1.781	19.05%	79.69%	11.60	0.467	1.92%	66.92%
zinc rougher - time 2 minutes	26.30	3.24%	59.60%	0.29	0.009	2.54%	85.48%	3.37	0.109	1.61%	90.20%	31.40	1.018	10.89%	90.57%	15.60	0.506	2.08%	69.00%
zinc scavenger - time 0.5 minutes	9.70	1.20%	60.80%	0.36	0.004	1.15%	86.64%	4.49	0.054	0.79%	90.99%	16.10	0.192	2.06%	92.63%	24.50	0.293	1.20%	70.20%
zinc scavenger - time 1 minute	9.10	1.12%	61.92%	0.33	0.004	1.00%	87.64%	4.14	0.046	0.69%	91.68%	22.70	0.255	2.72%	95.36%	21.70	0.243	1.00%	71.20%
final tails	309.93	38.08%	100.00%	0.12	0.046	12.36%	100.00%	1.48	0.564	8.32%	100.00%	1.14	0.434	4.64%	100.00%	18.40	7.097	28.80%	100.00%
test feed (reconstituted)	811.53				0.370	100.00%			6.772	100.00%			9.348	100.00%			24.329	100.00%	

TEST SUMMARY:

	sample weight	mass pull sample	mass pull total	copper assay %	recovery stage	recovery total	lead assay %	recovery stage	recovery total	zinc assay %	recovery stage	recovery total	iron assay %	recovery stage	recovery total
bulk flotation	88.80	10.94%	10.94%	1.82	53.73%	53.73%	36.34	58.71%	58.71%	9.26	10.84%	10.84%	22.95	10.32%	10.32%
pyrite rougher flotation in nitrogen	306.30	37.78%	48.69%	0.25	25.24%	78.97%	4.91	27.39%	86.10%	7.90	31.89%	42.73%	34.29	53.19%	63.51%
zinc rougher flotation	88.60	10.92%	59.60%	0.22	6.51%	85.48%	2.55	4.10%	90.20%	40.97	47.85%	90.57%	12.22	5.49%	69.00%
zinc scavenger flotation	18.80	2.32%	61.92%	0.35	2.16%	87.64%	4.32	1.48%	91.68%	19.29	4.78%	95.36%	23.14	2.20%	71.20%
final tails	309.93	38.08%	100.00%	0.12	12.36%	100.00%	1.48	8.32%	100.00%	1.14	4.64%	100.00%	18.40	28.80%	100.00%

10-214 Bulk copper,lead flotation in air, pyrite flotation in nitrogen, zinc flotation in air

FLOTATION CONDITIONS

sample reference	pH	activator added g/t	Pre-conditioning gas	Pre-conditioning time	collector type	collector addition g/t	flotation gas
bulk rougher - time 1.5 minutes	8.5	-	air	10 min	SIPX	50	air
bulk scavenger - time 1.5 minutes	8.5	-	-	-	SIPX	30	air
pyrite rougher - time 2 minutes A	8.5	-	nitrogen	4 min	SIPX	6	nitrogen
pyrite rougher - time 2 minutes B	8.5	-	nitrogen	4 min	SIPX	6	nitrogen
pyrite rougher - time 2 minutes C	8.5	-	nitrogen	4 min	SIPX	6	nitrogen
pyrite rougher - time 2 minutes D	8.5	-	nitrogen	4 min	SIPX	6	nitrogen
zinc rougher - time 30 seconds	10.0	1200	-	5 min	SIPX	50	air
zinc rougher - time 1 minute	10.0	-	-	-	-	-	air
zinc rougher - time 2 minutes	10.0	-	-	-	-	-	air
zinc scavenger - time 0.5 minutes	10.0	-	-	-	SIPX	30	air
zinc scavenger - time 1 minute	10.0	-	-	-	-	-	air

GRINDING CONDITIONS:

30 minutes, mild steel charge

Zinc Sulphate, 1200 g/t

10-214 Bulk copper,lead flotation in air, pyrite flotation in nitrogen, zinc flotation in air

sample reference	SOLIDS MASS BALANCE: sample weight (grams)	mass pull sample	mass pull total	COPPER MASS BALANCE: copper assay	copper units	copper recovery stage	copper recovery total	LEAD MASS BALANCE: lead assay	lead units	lead recovery stage	lead recovery total	ZINC MASS BALANCE: zinc assay	zinc units	zinc recovery stage	zinc recovery total	IRON MASS BALANCE: iron assay	iron units	iron recovery stage	iron recovery total
bulk rougher time 1.5 minutes	47.20	4.99%	4.99%	2.96	0.148	42.77%	42.77%	35.10	1.750	28.14%	28.14%	5.91	0.295	3.66%	3.66%	25.90	1.291	5.36%	5.36%
bulk scavenger - time 1.5 minutes	120.60	12.74%	17.72%	0.52	0.066	19.20%	61.97%	16.10	2.051	32.98%	61.12%	8.25	1.051	13.05%	16.71%	26.30	3.350	13.91%	19.27%
pyrite rougher - time 2 minutes A	25.90	2.74%	20.46%	0.53	0.014	4.20%	66.18%	10.50	0.287	4.62%	65.74%	[illegible]	0.298	3.70%	20.41%	28.80	0.789	3.27%	22.54%
pyrite rougher time 2 minutes B	16.90	1.79%	22.25%	0.54	0.010	2.79%	68.97%	9.50	0.170	2.73%	68.47%		0.216	2.69%	23.09%	29.30	0.523	2.17%	24.71%
pyrite rougher time 2 minutes C	9.80	1.04%	23.28%	0.51	0.005	1.53%	70.50%	8.78	0.091	1.46%	69.93%		0.129	1.61%	24.70%	28.40	0.294	1.22%	25.93%
pyrite rougher - time 2 minutes D	5.90	0.62%	23.90%	0.37	0.002	0.67%	71.17%	6.69	0.042	0.67%	70.60%	11.80	0.074	0.91%	25.61%	28.50	0.178	0.74%	26.67%
zinc rougher time 30 seconds	35.00	3.70%	27.60%	0.17	0.006	1.82%	72.99%	2.57	0.095	1.53%	72.13%	44.70	1.652	20.52%	46.13%	11.30	0.418	1.73%	28.40%
zinc rougher time 1 minute	44.30	4.68%	32.28%	0.21	0.010	2.85%	75.84%	2.95	0.138	2.22%	74.35%	39.90	1.867	23.18%	69.32%	12.90	0.604	2.51%	30.91%
zinc rougher time 2 minutes	28.40	3.00%	35.28%	0.23	0.007	2.00%	77.84%	3.81	0.114	1.84%	76.18%	32.20	0.966	11.99%	81.31%	18.10	0.543	2.25%	33.17%
zinc scavenger - time 0.5 minutes	18.10	1.91%	37.19%	0.23	0.004	1.27%	79.11%	4.26	0.081	1.31%	77.49%	24.70	0.472	5.86%	87.17%	23.90	0.457	1.90%	35.06%
zinc scavenger - time 1 minute	18.80	1.99%	39.18%	0.26	0.005	1.50%	80.61%	4.94	0.098	1.58%	79.07%	17.10	0.340	4.22%	91.39%	28.10	0.558	2.32%	37.38%
final tails	575.80	60.82%	100.00%	0.11	0.067	19.39%	100.00%	2.14	1.302	20.93%	100.00%	1.14	0.693	8.61%	100.00%	24.80	15.084	62.62%	100.00%
test feed (reconstituted)	946.70				0.345	100.00%			6.219	100.00%			8.054	100.00%			24.087	100.00%	

TEST SUMMARY:

	sample weight	mass pull sample	mass pull total	copper assay %	recovery stage	recovery total	lead assay %	recovery stage	recovery total	zinc assay %	recovery stage	recovery total	iron assay %	recovery stage	recovery total
bulk flotation	167.80	17.72%	17.72%	1.21	61.97%	61.97%	21.44	61.12%	61.12%	7.59	16.71%	16.71%	26.19	19.27%	19.27%
pyrite rougher flotation in nitrogen	58.50	6.18%	23.90%	0.51	9.20%	71.17%	9.54	9.48%	70.60%	11.61	8.90%	25.61%	28.85	7.40%	26.67%
zinc rougher flotation	107.70	11.38%	35.28%	0.20	6.67%	77.84%	3.05	5.59%	76.18%	39.43	55.70%	81.31%	13.75	6.49%	33.17%
zinc scavenger flotation	36.90	3.90%	39.18%	0.25	2.77%	80.61%	4.61	2.89%	79.07%	20.87	10.08%	91.39%	26.04	4.21%	37.38%
final tails	575.80	60.82%	100.00%	0.11	19.39%	100.00%	2.14	20.93%	100.00%	1.14	8.61%	100.00%	24.80	62.62%	100.00%

10-215 Bulk copper, lead flotation in air, pyrite flotation & zinc flotation in air.

FLOTATION CONDITIONS

sample reference	pH	activator added g/t	Pre-conditioning gas	Pre-conditioning time	collector type	collector addition g/t	flotation gas
bulk rougher - time 1.5 minutes	8.5	-	air	10 min	SIPX	50	air
bulk scavenger - time 1.5 minutes	8.5	-	-	-	SIPX	30	air
pyrite rougher - time 2 minutes A	8.5	-	air	4 min	SIPX	6	air
pyrite rougher - time 2 minutes B	8.5	-	air	4 min	SIPX	6	air
pyrite rougher - time 2 minutes C	8.5	-	air	4 min	SIPX	6	air
pyrite rougher - time 2 minutes D	8.5	-	air	4 min	SIPX	6	air
zinc rougher - time 30 seconds	10.0	1200	-	5 min	SIPX	50	air
zinc rougher - time 1 minute	10.0	-	-	-	-	-	air
zinc rougher - time 2 minutes	10.0	-	-	-	-	-	air
zinc scavenger - time 0.5 minutes	10.0	-	-	-	SIPX	30	air
zinc scavenger - time 1 minute	10.0	-	-	-	-	-	air

GRINDING CONDITIONS:

30 minutes, mild steel charge

Zinc Sulphate, 1200 g/t

10-215 Bulk copper,lead flotation in air, pyrite flotation & zinc flotation in air.

sample reference	SOLIDS MASS BALANCE: sample weight (grams)	mass pull: sample	mass pull: total	COPPER MASS BALANCE: copper assay (%)	copper units	copper recovery: stage	copper recovery: total	LEAD MASS BALANCE: lead assay (%)	lead units	lead recovery: stage	lead recovery: total
bulk rougher 2 minutes	138.55	14.39%	14.39%	1.48	0.213	67.23%	67.23%	13.60	1.957	65.53%	65.53%
bulk scavenger - 2 minutes	65.77	6.83%	21.22%	0.41	0.028	8.84%	76.07%	4.28	0.292	9.79%	75.32%
zinc rougher time 30 seconds	71.17	7.39%	28.62%	0.15	0.011	3.50%	79.57%	1.34	0.099	3.32%	78.64%
zinc rougher time 1 minute	52.89	5.49%	34.11%	0.18	0.010	3.12%	82.69%	1.60	0.088	2.94%	81.58%
zinc rougher time 2 minutes A	50.21	5.22%	39.33%	0.18	0.009	2.96%	85.66%	1.70	0.089	2.97%	84.55%
zinc rougher time 2 minutes B	28.52	2.96%	42.29%	0.18	0.005	1.68%	87.34%	1.64	0.049	1.63%	86.18%
zinc scavenger time 30 seconds	20.95	2.18%	44.47%	0.17	0.004	1.17%	88.51%	1.50	0.033	1.09%	87.27%
zinc scavenger time 1 minute	30.03	3.12%	47.59%	0.16	0.005	1.58%	90.08%	1.41	0.044	1.47%	88.74%
zinc scavenger time 2 minutes A	37.48	3.89%	51.48%	0.14	0.005	1.72%	91.80%	1.35	0.053	1.76%	90.50%
zinc scavenger time 2 minutes B	27.40	2.85%	54.32%	0.11	0.003	0.99%	92.79%	1.14	0.032	1.09%	91.59%
final tails	439.70	45.68%	100.00%	0.05	0.023	7.21%	100.00%	0.55	0.251	8.41%	100.00%
reconstituted feed	962.67				0.317	100.00%			2.987	100.00%	

sample reference	ZINC MASS BALANCE: zinc assay (%)	zinc units	zinc recovery: stage	zinc recovery: total	IRON MASS BALANCE: iron assay (%)	iron units	iron recovery: stage	iron recovery: total
bulk rougher 2 minutes	6.70	0.964	13.08%	13.08%	35.10	5.052	19.56%	19.56%
bulk scavenger - 2 minutes	9.30	0.635	8.62%	21.69%	31.20	2.132	8.25%	27.81%
zinc rougher time 30 seconds	35.60	2.632	35.69%	57.38%	14.70	1.087	4.21%	32.02%
zinc rougher time 1 minute	28.80	1.582	21.46%	78.83%	19.70	1.082	4.19%	36.21%
zinc rougher time 2 minutes A	15.60	0.814	11.03%	89.87%	25.70	1.340	5.19%	41.40%
zinc rougher time 2 minutes B	8.90	0.264	3.58%	93.44%	27.00	0.800	3.10%	44.50%
zinc scavenger time 30 seconds	5.20	0.113	1.53%	94.98%	34.40	0.749	2.90%	47.39%
zinc scavenger time 1 minute	3.49	0.109	1.48%	96.45%	35.10	1.095	4.24%	51.63%
zinc scavenger time 2 minutes A	2.41	0.094	1.27%	97.73%	33.60	1.308	5.06%	56.70%
zinc scavenger time 2 minutes B	1.40	0.040	0.54%	98.27%	33.50	0.953	3.69%	60.39%
final tails	0.28	0.128	1.73%	100.00%	22.40	10.231	39.61%	100.00%
reconstituted feed		7.375	100.00%			25.829	100.00%	

TEST SUMMARY	sample weight	mass pull: sample	mass pull: total	copper assay %	copper recovery: stage	copper recovery: total	lead assay %	lead recovery: stage	lead recovery: total	zinc assay %	zinc recovery: stage	zinc recovery: total	iron assay %	iron recovery: stage	iron recovery: total
bulk flotation	204.32	0.21	21.22%	1.14	76.07%	76.07%	10.69	75.32%	75.32%	7.54	21.69%	21.69%	33.84	27.81%	27.81%
zinc rougher flotation	202.79	0.21	42.29%	0.17	11.27%	87.34%	1.54	10.86%	86.18%	25.12	71.75%	93.44%	20.46	16.68%	44.50%
zinc scavenger flotation time 0-1.5 min	50.98	0.05	47.59%	0.16	2.74%	90.08%	1.45	2.57%	88.74%	4.19	3.01%	96.45%	34.81	7.14%	51.67%
zinc scavenger flotation time 1.5min+	64.88	0.07	54.32%	0.13	2.71%	92.79%	1.26	2.85%	91.59%	1.98	1.81%	98.27%	33.56	8.76%	60.39%
final flotation tails	439.70	0.46	100.00%	0.05	7.21%	100.00%	0.55	8.41%	100.00%	0.28	1.73%	100.00%	22.40	39.61%	100.00%

10-301 Standard bulk copper,lead flotation and zinc flotation.

sample reference	pH	activator added g/t	Pre-conditioning gas	Pre-conditioning time	collector type	collector addition g/t	flotation gas
bulk rougher - 2 minutes	8.5	-	air	10 min	SIPX	50	air
bulk scavenger - 2 minutes	8.5	-	-	-	SIPX	30	air
zinc rougher - 30 second	10.0	1200	none	5 min	SIPX	50	air
zinc rougher - 1 minute	10.0	-	-	-	-	-	air
zinc rougher - 2 minutes A	10.0	-	-	-	-	-	air
zinc rougher - 2 minutes B	10.0	-	-	-	-	-	air
zinc scavenger - 30 seconds	10.0	-	-	-	SIPX	30	air
zinc scavenger - 1 minute	10.0	-	-	-	-	-	air
zinc scavenger - 2 minutes A	10.0	-	-	-	-	-	air
zinc scavenger - 2 minutes B	10.0	-	-	-	-	-	air

GRINDING CONDITIONS:

30 minutes, mild steel charge

1200 g/t zinc sulphate

10-301 Standard bulk copper,lead flotation and zinc flotation.

sample reference	SOLIDS MASS BALANCE sample weight	mass pull sample	mass pull total	COPPER MASS BALANCE copper assay (%)	copper units	copper recovery stage	copper recovery total	LEAD MASS BALANCE lead assay (%)	lead units	lead recovery stage	lead recovery total	ZINC MASS BALANCE zinc assay (%)	zinc units	zinc recovery stage	zinc recovery total	IRON MASS BALANCE iron assay (%)	iron units	iron recovery stage	iron recovery total
bulk rougher - 30 seconds A	79.10	3.99%	3.99%	2.08	0.083	26.10%	26.10%	33.98	1.357	32.92%	32.92%	7.62	0.304	3.23%	3.23%	21.12	0.842	3.09%	3.09%
bulk rougher - 30 seconds B	54.60	2.76%	6.75%	1.78	0.049	15.42%	41.52%	24.38	0.672	16.30%	49.22%	8.60	0.237	2.52%	5.75%	25.94	0.715	2.62%	5.71%
bulk rougher - 1 minute A	75.80	3.83%	10.57%	0.98	0.037	11.78%	53.30%	14.66	0.561	13.61%	62.84%	10.40	0.398	4.23%	9.98%	29.84	1.142	4.19%	9.90%
bulk rougher - 1 minute B	114.60	5.78%	16.36%	0.65	0.038	12.00%	65.30%	7.92	0.458	11.12%	73.95%	10.10	0.584	6.21%	16.19%	34.12	1.974	7.23%	17.13%
bulk rougher - 2 minutes A	76.70	3.87%	20.23%	0.48	0.019	5.84%	71.14%	5.10	0.197	4.79%	78.75%	10.46	0.405	4.30%	20.49%	35.65	1.380	5.06%	22.19%
bulk rougher - 2 minutes B	60.00	3.03%	23.26%	0.28	0.008	2.67%	73.81%	3.92	0.119	2.88%	81.63%	10.80	0.327	3.48%	23.96%	36.68	1.111	4.07%	26.26%
pyrite rougher - 2 minutes A	31.00	1.56%	24.82%	0.20	0.003	0.98%	74.79%	2.69	0.042	1.02%	82.64%	9.66	0.151	1.61%	25.57%	37.54	0.587	2.15%	28.42%
pyrite rougher - 2 minutes B	58.50	2.95%	27.77%	0.22	0.006	2.04%	76.83%	2.26	0.067	1.62%	84.26%	8.44	0.249	2.65%	28.22%	39.54	1.167	4.28%	32.70%
pyrite rougher - 2 minutes C	45.50	2.30%	30.07%	0.18	0.004	1.30%	78.13%	1.82	0.042	1.01%	85.29%	8.22	0.189	2.01%	30.23%	38.00	0.874	3.21%	35.90%
pyrite rougher - 2 minutes D	42.80	2.16%	32.23%	0.16	0.003	1.09%	79.22%	1.62	0.035	0.85%	86.13%	8.10	0.177	1.88%	32.10%	40.14	0.867	3.18%	39.08%
pyrite rghr concentrate	177.80	8.97%		0.19		5.41%		2.07		4.50%		8.53		8.14%		38.96		12.82%	
zinc rougher - time 30 seconds	152.20	7.68%	39.91%	0.10	0.008	2.41%	81.63%	0.92	0.071	1.72%	87.84%	46.50	3.575	37.99%	70.09%	13.90	1.068	3.91%	43.00%
zinc rougher - time 30 seconds	56.10	2.83%	42.74%	0.12	0.003	1.07%	82.70%	1.00	0.028	0.69%	88.53%	45.84	1.298	13.79%	83.88%	14.58	0.413	1.51%	44.51%
zinc rougher - time 1 minute	43.10	2.19%	44.92%	0.14	0.003	0.96%	83.66%	1.44	0.031	0.76%	89.29%	36.68	0.798	8.48%	92.36%	19.32	0.420	1.54%	46.05%
zinc rougher - time 1 minute	39.00	1.97%	46.89%	0.18	0.004	1.11%	84.77%	1.82	0.036	0.87%	90.16%	17.20	0.339	3.60%	95.96%	31.50	0.620	2.27%	48.32%
zinc rougher - time 2 minutes	90.40	4.56%	51.45%	0.16	0.007	2.29%	87.07%	1.46	0.067	1.62%	91.78%	4.60	0.210	2.23%	98.19%	42.18	1.925	7.06%	55.39%
zinc rougher - time 2 minutes	45.70	2.31%	53.76%	0.18	0.004	1.30%	88.37%	1.46	0.034	0.82%	92.59%	2.58	0.060	0.63%	98.82%	42.16	0.972	3.56%	58.94%
final tails	916.20	46.24%	100.00%	0.08	0.037	11.63%	100.00%	0.66	0.305	7.41%	100.00%	0.24	0.111	1.18%	100.00%	24.22	11.200	41.06%	100.00%
reconstituted feed	1981.30				0.318	100.00%			4.121	100.00%			9.411	100.00%			27.279	100.00%	

TEST SUMMARY:	sample weight	mass pull sample	mass pull total	copper assay %	copper recovery stage	copper recovery total	lead assay %	lead recovery stage	lead recovery total	zinc assay %	zinc recovery stage	zinc recovery total	iron assay %	iron recovery stage	iron recovery total
bulk flotation	460.90	23.26%	23.26%	1.01	73.81%	73.81%	14.46	81.63%	81.63%	9.70	23.96%	23.96%	30.80	26.26%	26.26%
pyrite final concentrate	177.80	8.97%	32.23%	0.19	5.41%	79.22%	2.07	4.50%	86.13%	8.53	8.14%	32.10%	38.96	12.82%	39.08%
zinc rougher flotation	380.80	19.22%	51.45%	0.13	7.85%	87.07%	1.21	5.65%	91.78%	32.36	66.09%	98.19%	23.13	16.30%	55.38%
final flotation tails (incl. last Zn conc.)	961.90	48.55%	100.00%	0.08	12.93%	100.00%	0.70	8.22%	100.00%	0.35	1.81%	100.90%	25.07	44.62%	100.00%

10-401 Bulk copper, lead flotation in air, pyrite flotation in air and zinc flotation.

FLOTATION CONDITIONS

sample reference	pH	activator added g/t	Pre-conditioning gas	Pre-conditioning time	collector type	collector addition g/t	flotation gas
bulk rougher - 30 seconds A	9.1	-	air	20 min	SIPX/SAX	40	air
bulk rougher - 30 seconds B	9.1	-	-	-	-	-	air
bulk rougher - 1 minute A	9.1	-	-	-	SIPX/SAX	5	air
bulk rougher - 1 minute B	9.1	-	-	-	-	-	air
bulk rougher - 2 minutes A	9.1	-	-	-	SIPX/SAX	5	air
bulk rougher - 2 minutes B	9.1	-	-	-	SIPX/SAX	5	air
pyrite rougher - 2 minutes A	9.1	-	-	4 min	SIPX/SAX	6	air
pyrite rougher - 2 minutes B	9.1	-	-	4 min	SIPX/SAX	6	air
pyrite rougher - 2 minutes C	9.1	-	-	4 min	SIPX/SAX	6	air
pyrite rougher - 2 minutes D	9.1	-	-	4 min	SIPX/SAX	6	air
zinc rougher - 30 seconds A	10.2	630	none	10 min	SIPX/SAX	25	air
zinc rougher - 30 seconds B	10.2	-	-	-	-	-	air
zinc rougher - 1 minute A	10.2	-	-	-	-	-	air
zinc rougher - 1 minute B	10.2	-	-	-	SIPX/SAX	5	air
zinc rougher - 2 minutes A	10.2	-	-	-	-	-	air
zinc rougher - 2 minutes B	10.2	-	-	-	SIPX/SAX	5	air

NOTE:

Soda ash used for pH adjustment during bulk flotation

Lime used for pH adjustment during zinc flotation

GRINDING CONDITIONS:

25 minutes, mild steel charge, BMS mill

150 g/t sulphur dioxide

10-401 Bulk copper, lead flotation in air, pyrite flotation in air and zinc flotation.

sample reference	SOLIDS MASS BALANCE sample weight	mass pull sample	mass pull total	COPPER MASS BALANCE copper assay (%)	copper units	copper recovery stage	copper recovery total	LEAD MASS BALANCE lead assay (%)	lead units	lead recovery stage	lead recovery total	ZINC MASS BALANCE zinc assay (%)	zinc units	zinc recovery stage	zinc recovery total	IRON MASS BALANCE iron assay (%)	iron units	iron recovery stage	iron recovery total
bulk rougher 30 seconds A	98.00	5.28%	5.28%	1.64	0.067	24.71%	24.71%	29.31	1.549	39.91%	39.91%	8.30	0.479	4.80%	4.80%	23.44	1.278	4.82%	4.82%
bulk rougher 30 seconds B	45.70	2.46%	7.75%	1.76	0.047	12.37%	37.08%	19.58	0.482	12.43%	52.34%	8.52	0.210	2.30%	7.10%	27.88	0.687	2.68%	7.50%
bulk rougher 1 minute A	95.70	5.17%	12.89%	1.06	0.054	15.52%	52.59%	10.02	0.514	13.25%	65.60%	9.86	0.506	5.54%	12.64%	30.44	1.562	6.99%	13.57%
bulk rougher 1 minute B	77.70	4.19%	17.07%	0.80	0.034	9.56%	62.15%	7.18	0.301	7.75%	73.35%	10.16	0.426	4.66%	17.30%	33.22	1.392	5.42%	19.01%
bulk rougher 2 minutes A	108.90	5.87%	22.94%	0.46	0.027	7.70%	69.85%	4.80	0.282	7.26%	80.61%	10.22	0.600	6.57%	23.87%	33.72	1.980	7.71%	26.72%
bulk rougher 2 minutes B	51.00	2.75%	25.69%	0.44	0.012	3.45%	73.30%	4.34	0.119	3.08%	83.68%	10.50	0.289	3.16%	27.03%	31.80	0.874	3.41%	30.17%
pyrite rougher 2 minutes A	70.60	3.81%	29.49%	0.20	0.008	2.17%	75.47%	2.22	0.084	2.18%	85.86%	8.34	0.317	3.49%	30.51%	31.92	1.215	4.73%	34.86%
pyrite rougher 2 minutes B	135.70	7.32%	36.81%	0.18	0.013	3.76%	79.22%	1.14	0.083	2.15%	88.01%	5.40	0.395	4.32%	34.84%	38.10	2.787	10.86%	45.72%
pyrite rougher - 2 minutes C	228.80	12.33%	49.15%	0.16	0.020	5.63%	84.86%	1.00	0.123	3.18%	91.19%	5.30	0.654	7.16%	41.99%	38.98	4.808	18.73%	64.45%
pyrite rougher - 2 minutes D	241.50	13.02%	62.17%	0.16	0.021	5.94%	90.80%	0.90	0.117	3.02%	94.21%	10.34	1.346	14.74%	56.74%	35.86	4.669	18.19%	82.64%
pyrite cobr concentrate	676.60	36.48%		0.17		17.50%		1.12		10.53%		7.44		29.70%		36.95		52.51%	
zinc rougher time 30 seconds	92.40	4.98%	67.15%	0.14	0.007	1.99%	92.79%	0.72	0.036	0.92%	95.14%	46.32	2.307	25.27%	82.00%	11.78	0.587	2.29%	84.92%
zinc rougher - time 30 seconds	39.40	2.12%	69.27%	0.16	0.003	0.97%	93.76%	0.84	0.018	0.46%	95.59%	45.38	0.964	10.56%	92.56%	11.68	0.249	0.97%	85.89%
zinc rougher - time 1 minute	21.60	1.16%	70.44%	0.12	0.001	0.40%	94.16%	1.16	0.014	0.35%	95.94%	34.12	0.397	4.35%	96.91%	16.78	0.195	0.76%	86.65%
zinc rougher time 1 minute	23.60	1.27%	71.71%	0.14	0.002	0.51%	94.66%	1.18	0.015	0.39%	96.33%	7.22	0.092	1.01%	97.91%	29.00	0.769	1.44%	88.09%
zinc rougher - time 2 minutes	44.40	2.39%	74.10%	0.12	0.003	0.82%	95.48%	1.06	0.025	0.65%	96.98%	2.80	0.067	0.73%	98.65%	28.50	0.682	2.66%	90.75%
zinc rougher - time 2 minutes	9.20	0.50%	74.60%	0.12	0.001	0.17%	95.65%	1.06	0.005	0.14%	97.12%	2.38	0.012	0.13%	98.78%	28.16	0.140	0.54%	91.29%
final tails	471.20	25.40%	100.00%	0.06	0.015	4.35%	100.00%	0.44	0.112	2.88%	100.00%	0.44	0.112	1.22%	100.00%	8.80	2.235	8.71%	100.00%
reconstituted feed	1854.90				0.351	100.00%			3.880	100.00%			9.132	100.00%			25.669	100.00%	

TEST SUMMARY:	sample weight	mass pull sample	mass pull total	copper assay %	copper recovery stage	copper recovery total	lead assay %	lead recovery stage	lead recovery total	zinc assay %	zinc recovery stage	zinc recovery total	iron assay %	iron recovery stage	iron recovery total
bulk flotation	476.50	25.69%	25.69%	1.00	73.30%	73.30%	12.64	83.68%	83.68%	9.61	27.03%	27.03%	30.10	30.17%	30.17%
pyrite flotation	676.60	36.48%	62.17%	0.17	17.50%	90.80%	1.12	10.53%	94.21%	7.44	29.70%	56.74%	36.95	52.51%	82.69%
zinc rougher flotation	221.40	11.94%	74.10%	0.14	4.68%	95.48%	0.90	2.77%	96.98%	32.07	41.91%	98.65%	17.44	8.11%	90.75%
final flotation tails	480.40	25.90%	100.00%	0.06	4.52%	100.00%	0.45	3.02%	100.00%	0.48	1.35%	100.00%	9.17	9.25%	100.00%

10-402 Bulk copper,lead flotation in air, pyrite flotation in nitrogen and zinc flotation

test number	FLOTATION CONDITIONS						
sample reference	pH	activator added g/t	Pre-conditioning gas	Pre-conditioning time	collector type	collector addition g/t	flotation gas
bulk rougher - 30 seconds A	9.1	-	air	20 min	SIPX/SAX	40	air
bulk rougher - 30 seconds B	9.1	-	-	-	-	-	air
bulk rougher - 1 minute A	9.1	-	-	-	SIPX/SAX	5	air
bulk rougher - 1 minute B	9.1	-	-	-	-	-	air
bulk rougher - 2 minutes A	9.1	-	-	-	SIPX/SAX	5	air
bulk rougher - 2 minutes B	9.1	-	-	-	SIPX/SAX	5	air
pyrite rougher - 2 minutes A	9.1	-	nitrogen	4 min	SIPX/SAX	6	nitrogen
pyrite rougher - 2 minutes B	9.1	-	nitrogen	4 min	SIPX/SAX	6	nitrogen
pyrite rougher - 2 minutes C	9.1	-	nitrogen	4 min	SIPX/SAX	6	nitrogen
pyrite rougher - 2 minutes D	9.1	-	nitrogen	4 min	SIPX/SAX	6	nitrogen
zinc rougher - 30 seconds A	10.2	630	none	10 min	SIPX/SAX	25	air
zinc rougher - 30 seconds B	10.2	-	-	-	-	-	air
zinc rougher - 1 minute A	10.2	-	-	-	-	-	air
zinc rougher - 1 minute B	10.2	-	-	-	SIPX/SAX	5	air
zinc rougher - 2 minutes A	10.2	-	-	-	-	-	air
zinc rougher - 2 minutes B	10.2	-	-	-	SIPX/SAX	5	air

NOTE:

Soda ash used for pH adjustment during bulk flotation

Lime used for pH adjustment during zinc flotation

GRINDING CONDITIONS:

25 minutes, mild steel charge, BMS mill

150 g/t sulphur dioxide

10-402 Bulk copper,lead flotation in air, pyrite flotation in nitrogen and zinc flotation

sample reference	SOLIDS MASS BALANCE sample weight	mass pull sample	mass pull total	COPPER MASS BALANCE copper assay (%)	copper units	copper recovery stage	copper recovery total	LEAD MASS BALANCE lead assay (%)	lead units	lead recovery stage	lead recovery total
bulk rougher 30 seconds A	101.10	5.06%	5.06%	2.52	0.128	32.84%	32.84%	28.40	1.438	38.20%	38.20%
bulk rougher 30 seconds B	37.70	1.89%	6.95%	1.84	0.035	8.94%	41.78%	19.60	0.370	9.83%	48.03%
bulk rougher 1 minute A	64.70	3.24%	10.19%	1.12	0.036	9.34%	51.12%	15.10	0.489	13.00%	61.02%
bulk rougher 1 minute B	87.90	4.40%	14.59%	0.84	0.037	9.52%	60.63%	8.35	0.367	9.76%	70.79%
bulk rougher 2 minutes A	108.90	5.45%	20.04%	0.47	0.026	6.60%	67.23%	5.15	0.281	7.46%	78.25%
bulk rougher 2 minutes B	41.30	2.07%	22.11%	0.45	0.009	2.40%	69.63%	3.70	0.077	2.03%	80.28%
pyrite conc Zn scavenger 1	16.39	0.82%	22.93%	0.14	0.001	0.29%	69.92%	1.30	0.011	0.30%	80.58%
pyrite conc Zn scavenger 2	24.29	1.21%	24.14%	0.15	0.002	0.47%	70.39%	1.94	0.024	0.62%	81.21%
pyrite conc Zn scavenger 3	43.30	2.17%	26.31%	0.21	0.005	1.17%	71.56%	2.39	0.052	1.38%	82.58%
pyrite final conc (Zn scav tails)	513.80	25.73%	52.03%	0.17	0.044	11.26%	82.82%	1.22	0.314	8.34%	90.92%
pyrite rghr concentrate	597.60	29.92%		0.17		13.19%		1.34		10.64%	
zinc rougher - time 30 seconds	103.20	5.17%	57.20%	0.16	0.008	2.13%	84.95%	0.79	0.041	1.08%	92.01%
zinc rougher time 30 seconds	46.60	2.33%	59.53%	0.13	0.003	0.78%	85.73%	0.79	0.018	0.49%	92.50%
zinc rougher time 1 minute	34.09	1.70%	61.24%	0.17	0.003	0.74%	86.47%	1.02	0.017	0.46%	92.96%
zinc rougher time 1 minute	28.50	1.43%	62.66%	0.20	0.003	0.73%	87.21%	1.52	0.022	0.58%	93.53%
zinc rougher time 2 minutes	21.80	1.09%	63.75%	0.19	0.002	0.53%	87.74%	1.57	0.017	0.46%	93.99%
zinc rougher time 2 minutes	33.50	1.68%	65.43%	0.16	0.003	0.69%	88.43%	1.33	0.022	0.59%	94.58%
final tails	690.40	34.57%	100.00%	0.13	0.045	11.57%	100.00%	0.59	0.204	5.42%	100.00%
reconstituted feed	1997.20				0.388	100.00%			3.764	100.00%	

sample reference	ZINC MASS BALANCE zinc assay (%)	zinc units	zinc recovery stage	zinc recovery total	IRON MASS BALANCE iron assay (%)	iron units	iron recovery stage	iron recovery total
bulk rougher 30 seconds A	7.56	0.383	4.53%	4.53%	20.20	1.023	4.33%	4.33%
bulk rougher 30 seconds B	8.36	0.158	1.87%	6.40%	22.20	0.419	1.77%	6.10%
bulk rougher 1 minute A	10.30	0.334	3.95%	10.36%	25.50	0.826	3.50%	9.60%
bulk rougher 1 minute B	10.30	0.453	5.37%	15.73%	29.70	1.307	5.53%	15.13%
bulk rougher 2 minutes A	11.20	0.611	7.24%	22.97%	30.60	1.668	7.06%	22.19%
bulk rougher 2 minutes B	11.10	0.230	2.72%	25.69%	31.70	0.656	2.77%	24.96%
pyrite conc Zn scavenger 1	42.60	0.348	4.12%	29.81%	13.60	0.111	0.47%	25.43%
pyrite conc Zn scavenger 2	39.30	0.476	5.64%	35.45%	17.10	0.207	0.88%	26.31%
pyrite conc Zn scavenger 3	21.80	0.473	5.60%	41.05%	26.50	0.575	2.43%	28.74%
pyrite final conc (Zn scav tails)	1.64	0.422	5.00%	46.05%	37.50	9.647	40.83%	69.57%
pyrite rghr concentrate	5.74		20.36%		35.22		44.60%	
zinc rougher - time 30 seconds	41.50	2.144	25.41%	71.46%	10.20	0.527	2.23%	71.80%
zinc rougher time 30 seconds	42.60	0.994	11.78%	83.24%	10.80	0.252	1.07%	72.86%
zinc rougher time 1 minute	41.00	0.698	8.27%	91.51%	13.30	0.226	0.96%	73.82%
zinc rougher time 1 minute	25.30	0.361	4.28%	95.79%	19.5	0.278	1.18%	75.00%
zinc rougher time 2 minutes	17.90	0.195	2.32%	98.11%	20.80	0.227	0.96%	75.96%
zinc rougher time 2 minutes	4.38	0.073	0.87%	98.98%	27.50	0.461	1.95%	77.91%
final tails	0.25	0.086	1.02%	100.00%	15.10	5.220	22.09%	100.00%
reconstituted feed		8.439	100.00%			23.631	100.00%	

TEST SUMMARY:

	sample weight	mass pull sample	mass pull total	copper assay %	copper recovery stage	copper recovery total	lead assay %	lead recovery stage	lead recovery total	zinc assay %	zinc recovery stage	zinc recovery total	iron assay %	iron recovery stage	iron recovery total
bulk flotation	441.60	22.11%	22.11%	1.22	69.63%	69.63%	13.67	80.28%	80.28%	9.00	25.69%	25.69%	26.60	24.96%	24.96%
pyrite final concentrate	513.80	25.73%	47.84%	0.17	11.26%	80.88%	1.22	8.34%	88.62%	1.64	5.00%	30.69%	37.50	40.83%	65.79%
zinc from pyrite float	83.80	4.20%		0.18	1.93%		2.06	2.30%		30.90	15.36%		21.20	3.78%	
zinc rougher flotation	234.10	11.72%		0.16	4.92%		0.98	3.07%		37.48	52.05%		12.09	6.39%	
zinc combined concentrate	317.90	15.92%	63.75%	0.17	6.86%	87.74%	1.27	5.37%	93.99%	35.74	67.42%	98.11%	15.10	10.17%	75.96%
final flotation tails (incl last zinc con)	723.90	36.25%	100.00%	0.13	12.26%	100.00%	0.62	6.01%	100.00%	0.44	1.89%	100.00%	15.67	24.04%	100.00%

10-403 Bulk copper,lead flotation in air, pyrite flotation in nitrogen with zinc reverse cleaning, and zinc flotation in air

FLOTATION CONDITIONS

sample reference	pH	activator added g/t	Pre-conditioning gas	Pre-conditioning time	collector type	collector addition g/t	flotation gas
bulk rougher - 30 seconds A	9.1	-	air	20 min	SIPX/SAX	40	air
bulk rougher - 30 seconds B	9.1	-	-	-	-	-	air
bulk rougher - 1 minute A	9.1	-	-	-	SIPX/SAX	5	air
bulk rougher - 1 minute B	9.1	-	-	-	-	-	air
bulk rougher - 2 minutes A	9.1	-	-	-	SIPX/SAX	5	air
bulk rougher - 2 minutes B	9.1	-	-	-	SIPX/SAX	5	air
pyrite rougher - 2 minutes A	8.9	-	nitrogen	4 min	SIPX/SAX	6	nitrogen
pyrite rougher - 2 minutes B	8.9	-	nitrogen	4 min	SIPX/SAX	6	nitrogen
pyrite rougher - 2 minutes C	8.9	-	nitrogen	4 min	SIPX/SAX	6	nitrogen
pyrite rougher - 2 minutes D	8.9	-	nitrogen	4 min	SIPX/SAX	6	nitrogen
zinc rougher - 30 seconds A	10.2	630	none	10 min	SIPX/SAX	25	air
zinc rougher - 30 seconds B	10.2	-	-	-	-	-	air
zinc rougher - 1 minute A	10.2	-	-	-	-	-	air
zinc rougher - 1 minute B	10.2	-	-	-	SIPX/SAX	5	air
zinc rougher - 2 minutes A	10.2	-	-	-	-	-	air
zinc rougher - 2 minutes B	10.2	-	-	-	SIPX/SAX	5	air
zinc reverse flotation - 30 seconds	10.5	100	air	5 min	SIPX/SAX	5	air
zinc reverse flotation - 1 minute	10.5	-	-	-	-	-	air
zinc reverse flotation - 2 minutes	10.5	-	-	-	-	-	air

NOTE:

Soda ash used for pH adjustment during bulk flotation

Lime used for pH adjustment during zinc flotation

GRINDING CONDITIONS:

25 minutes, mild steel charge, RMS mill

150 g/t sulphur dioxide

10-403 Bulk copper, lead flotation in air, pyrite flotation in nitrogen with zinc reverse cleaning, and zinc flotation in air

sample reference	SOLIDS MASS BALANCE sample weight	mass pull sample	mass pull total	COPPER MASS BALANCE copper assay (%)	units	copper recovery stage	copper recovery total	LEAD MASS BALANCE lead assay (%)	units	lead recovery stage	lead recovery total	ZINC MASS BALANCE zinc assay (%)	units	zinc recovery stage	zinc recovery total	IRON MASS BALANCE iron assay (%)	units	iron recovery stage	iron recovery total
bulk rougher - 2 minutes (A)	97.00	4.86%	4.86%	2.62	0.127	32.47%	32.47%	27.30	1.328	34.53%	34.53%	5.68	0.276	3.24%	3.24%	18.90	0.919	3.85%	3.85%
bulk rougher - 2 minutes (B)	100.00	9.03%	13.89%	1.10	0.099	25.29%	57.76%	14.10	1.273	33.10%	67.63%	10.50	0.948	11.12%	14.37%	25.20	2.275	9.53%	13.39%
bulk scavenger - 2 minutes (A)	27.00	1.35%	15.25%	0.60	0.008	2.07%	59.83%	8.66	0.117	3.05%	70.68%	10.70	0.145	1.70%	16.07%	26.30	0.356	1.49%	14.88%
bulk scavenger - 2 minutes (B)	77.50	3.89%	19.13%	0.46	0.018	4.55%	64.39%	4.70	0.183	4.75%	75.43%	9.15	0.356	4.17%	20.24%	32.20	1.252	5.24%	20.12%
bulk scavenger - 2 minutes (C)	154.90	7.77%	26.90%	0.27	0.021	5.34%	69.73%	2.59	0.201	5.23%	80.66%	7.04	0.547	6.42%	26.66%	35.10	2.727	11.43%	31.55%
bulk scavenger - 2 minutes (D)	237.10	11.89%	38.79%	0.15	0.018	4.54%	74.27%	1.57	0.187	4.85%	85.51%	5.72	0.680	7.98%	34.64%	35.70	4.245	17.79%	49.34%
zinc rougher - time 30 seconds	99.60	4.99%	43.79%	0.18	0.009	2.29%	76.56%	1.12	0.056	1.45%	86.97%	39.70	1.983	23.27%	57.91%	11.20	0.559	2.34%	51.69%
zinc rougher - time 1 minute	101.10	5.07%	48.86%	0.22	0.011	2.84%	79.40%	1.31	0.066	1.73%	88.69%	38.40	1.947	22.85%	80.76%	13.20	0.669	2.80%	54.49%
zinc rougher - time 2 minutes A	74.70	3.75%	52.60%	0.26	0.010	2.48%	81.88%	1.64	0.061	1.60%	90.29%	29.20	1.094	12.84%	93.60%	18.20	0.682	2.86%	57.34%
zinc rougher - time 2 minutes B	37.20	1.87%	54.47%	0.24	0.004	1.14%	83.03%	1.76	0.033	0.85%	91.15%	11.70	0.218	2.56%	96.16%	24.80	0.463	1.94%	59.28%
zinc scavenger - time 30 seconds	22.50	1.13%	55.60%	0.27	0.003	0.78%	83.80%	1.59	0.018	0.47%	91.61%	6.11	0.069	0.81%	96.97%	28.90	0.326	1.37%	60.65%
zinc scavenger - time 1 minute	23.70	1.19%	56.79%	0.26	0.003	0.79%	84.59%	1.69	0.020	0.52%	92.13%	3.91	0.046	0.55%	97.51%	30.20	0.359	1.50%	62.15%
final tails	861.70	43.21%	100.00%	0.14	0.061	15.41%	100.00%	0.70	0.303	7.87%	100.00%	0.49	0.212	2.49%	100.00%	20.90	9.932	37.85%	100.00%
reconstituted feed	1994.00				0.393	100.00%			3.846	100.00%			8.521	100.00%			23.864	100.00%	

TEST SUMMARY:	sample weight	mass pull sample	mass pull total	copper assay %	recovery stage	recovery total	lead assay %	recovery stage	recovery total	zinc assay %	recovery stage	recovery total	iron assay %	recovery stage	recovery total
bulk flotation	277.00	13.89%	13.89%	1.63	57.76%	57.76%	18.72	67.63%	67.63%	8.81	14.37%	14.37%	22.99	13.39%	13.39%
pyrite flotation	496.50	24.90%	38.79%	0.26	16.51%	74.27%	2.76	17.88%	85.51%	6.94	20.27%	34.64%	34.46	35.95%	49.34%
zinc rougher flotation	312.60	15.68%	54.47%	0.22	8.75%	83.03%	1.38	5.63%	91.15%	33.44	61.52%	96.16%	15.14	9.94%	59.28%
zinc scavenger flotation	46.20	2.32%	56.79%	0.26	1.56%	84.59%	1.64	0.99%	92.13%	4.98	1.35%	97.51%	29.57	2.87%	62.15%
final flotation tails	861.70	43.21%	100.00%	0.14	15.41%	100.00%	0.70	7.87%	100.00%	0.49	2.49%	100.00%	20.90	37.85%	100.00%

10-404 Bulk copper, lead flotation in air, pyrite flotation in nitrogen and zinc flotation in air.

(McGill procedure)

FLOTATION CONDITIONS

sample reference	pH	activator added g/t	Pre-conditioning gas	Pre-conditioning time	collector type	collector addition g/t	flotation gas
bulk rougher - time 2 minutes	8.5	-	air	10 min	SIPX	25	air
bulk scavenger - time 2 minutes	8.5	-	-	-	SIPX	15	air
pyrite rougher - time 2 minutes A	8.5	-	nitrogen	5 min	SIPX	6	nitrogen
pyrite rougher - time 2 minutes B	8.5	-	nitrogen	4 min	SIPX	6	nitrogen
pyrite rougher - time 2 minutes C	8.5	-	nitrogen	4 min	SIPX	6	nitrogen
pyrite rougher - time 2 minutes D	8.5	-	nitrogen	4 min	SIPX	6	nitrogen
zinc rougher - time 30 seconds	10.5	1200	-	5 min	SIPX	50	air
zinc rougher - time 1 minute	10.5	-	-	-	-	-	air
zinc rougher - time 2 minutes	10.5	-	-	-	-	-	air
zinc rougher - time 2 minutes	10.5	-	-	-	-	-	air
zinc scavenger - time 0.5 minutes	10.5	-	-	-	SIPX	30	air
zinc scavenger - time 1 minute	10.5	-	-	-	-	-	air

GRINDING CONDITIONS:

25 minutes, mild steel charge, BMS mill

Zinc Sulphate, 120 g/t

10-404 Bulk copper,lead flotation in air, pyrite flotation in nitrogen and zinc flotation in air.

sample reference	SOLIDS MASS BALANCE sample weight (grams)	mass pull sample	mass pull total	COPPER MASS BALANCE copper assay (%)	copper units	copper recovery stage	copper recovery total	LEAD MASS BALANCE lead assay (%)	lead units	lead recovery stage	lead recovery total	ZINC MASS BALANCE zinc assay (%)	zinc units	zinc recovery stage	zinc recovery total	IRON MASS BALANCE iron assay (%)	iron units	iron recovery stage	iron recovery total
bulk rougher 2 minutes	58.44	5.45%	5.45%	3.39	0.185	57.97%	57.97%	17.20	0.937	37.06%	37.06%	6.80	0.371	3.98%	3.99%	25.00	1.763	5.55%	5.55%
bulk scavenger - 2 minutes	50.74	4.73%	10.18%	0.75	0.035	11.14%	69.11%	9.34	0.442	17.48%	54.54%	9.80	0.464	4.98%	8.96%	27.00	1.270	5.20%	10.75%
pyrite conc In scavenger 1	14.58	1.36%	11.54%	0.25	0.003	1.07%	70.17%	5.42	0.074	2.91%	57.45%	32.80	0.446	4.79%	13.75%	22.30	0.303	1.23%	11.98%
pyrite conc In scavenger 2	0.09	0.00%	11.54%	0.00	0.000	0.00%	70.17%	0.00	0.000	0.00%	57.45%	0.00	0.000	0.00%	13.75%	0.00	0.000	0.00%	11.98%
pyrite final conc (In scav tails)	410.49	38.28%	49.82%	0.11	0.042	13.21%	83.38%	1.50	0.574	22.70%	80.15%	4.97	1.902	20.43%	34.18%	38.10	14.584	59.36%	71.34%
pyrite rghr concentrate	424.98	39.64%		0.11		14.28%		1.63		25.61%		5.92		25.22%		37.56		60.59%	
zinc rougher time 30 seconds	30.22	2.82%	52.64%	0.18	0.005	1.59%	84.97%	1.09	0.031	1.21%	81.37%	58.40	1.646	17.68%	51.86%	9.14	0.258	1.05%	72.39%
zinc rougher time 1 minute	30.72	2.87%	55.50%	0.20	0.006	1.80%	86.77%	1.26	0.036	1.43%	82.80%	49.20	1.410	15.14%	67.00%	9.71	0.278	1.13%	73.52%
zinc rougher - time 2 minutes	42.45	3.96%	59.46%	0.19	0.008	2.36%	89.13%	1.46	0.058	2.29%	85.08%	35.70	1.413	15.18%	82.17%	12.60	0.499	2.03%	75.55%
zinc scavenger - time 30 seconds	20.30	1.89%	61.36%	0.20	0.004	1.19%	90.32%	1.73	0.033	1.29%	86.38%	31.40	0.595	6.38%	88.56%	16.90	0.320	1.30%	76.85%
zinc scavenger - time 1 minute	16.24	1.51%	62.87%	0.21	0.003	1.00%	91.32%	1.94	0.029	1.16%	87.54%	25.90	0.392	4.21%	92.77%	20.60	0.312	1.27%	78.12%
zinc scavenger - time 2 minutes	22.59	2.11%	64.98%	0.15	0.003	0.99%	92.31%	1.83	0.039	1.52%	89.06%	12.00	0.253	2.72%	95.49%	22.40	0.472	1.92%	80.04%
final tails	375.50	35.02%	100.00%	0.07	0.025	7.69%	100.00%	0.79	0.277	10.94%	100.00%	1.20	0.420	4.51%	100.00%	14.00	4.903	19.96%	100.00%
reconstituted feed	1072.18				0.319	100.00%			2.529	100.00%			9.312	100.00%			24.569	100.00%	

TEST SUMMARY:	sample weight	mass pull sample	mass pull total	copper assay %	recovery stage	recovery total	lead assay %	recovery stage	recovery total	zinc assay %	recovery stage	recovery total	iron assay %	recovery stage	recovery total
bulk flotation	109.18	10.18%	10.18%	2.16	69.11%	69.11%	13.55	54.54%	54.54%	8.19	8.96%	8.96%	25.93	10.75%	10.75%
pyrite flotation	424.98	1.36%	11.54%	0.25	1.07%	70.17%	5.42	2.91%	57.45%	32.80	4.79%	13.75%	22.30	1.23%	11.98%
zinc rougher flotation	103.39	47.92%	59.46%	0.13	18.96%	89.13%	1.46	27.63%	85.08%	13.30	68.42%	82.17%	32.59	63.57%	75.55%
zinc scavenger flotation time 0 1.5 min	59.13	5.51%	64.98%	0.18	3.18%	92.31%	1.83	3.98%	89.06%	22.48	13.31%	95.49%	20.02	4.49%	80.04%
final flotation tails	375.50	35.02%	100.00%	0.07	7.69%	100.00%	0.79	10.94%	100.00%	1.29	4.51%	100.00%	14.00	19.96%	100.00%

10-501 Bulk copper,lead flotation in air, pyrite flotation in argon and zinc flotation in air.

F L O T A T I O N   C O N D I T I O N S

sample reference	pH	activator added g/t	Pre-conditioning gas	Pre-conditioning time	collector type	collector addition g/t	flotation gas
bulk rougher - time 2 minutes	8.5	-	air	10 min	SIPX	50	air
bulk scavenger - time 2 minutes	8.5	-	-	-	SIPX	30	air
pyrite rougher - time 2 minutes A	8.5	-	argon	2 min	SIPX	20	argon
pyrite rougher - time 2 minutes B	8.5	-	argon	2 min	SIPX	20	argon
pyrite rougher - time 2 minutes C	8.5	-	argon	2 min	SIPX	5	argon
pyrite rougher - time 2 minutes D	8.5	-	argon	2 min	SIPX	5	argon
zinc rougher - time 30 seconds	10.0	1200	-	5 min	SIPX	50	air
zinc rougher - time 1 minute	10.0	-	-	-	-	-	air
zinc rougher - time 2 minutes	10.0	-	-	-	-	-	air
zinc scavenger - time 0.5 minutes	10.0	-	-	-	SIPX	30	air
zinc scavenger - time 1 minute	10.0	-	-	-	-	-	air
zinc reverse rougher - 1 minute	10.0	200	none	5 min	SIPX	8	air
zinc reverse scavenger - 1 minute	10.0	-	-	-	-	-	air

GRINDING CONDITIONS:

30 minutes, mild steel charge

Zinc Sulphate, 1200 g/t

10-501 Bulk copper,lead flotation in air, pyrite flotation in argon and zinc flotation in air.

11. APPENDIX 3 ; MATTABI ORE TESTWORK

EFFECT OF COLLECTOR AND SULPHITE ADDITION.

11-101 Bulk copper, lead flotation in air with 40 g/tonne collector and 3 kg/tonne sodium sulphite, the zinc flotation in air.

11-102 Bulk copper, lead flotation in air with 40 g/tonne collector and 1.5 kg/tonne sodium sulphite, then zinc flotation in air.

11-103 Bulk copper, lead flotation in air with 5 g/tonne collector and 1.5 kg/tonne sodium sulphite, then zinc flotation in air.

11-104 Bulk copper, lead flotation in air with 5 g/tonne collector and 1.0 kg/tonne sodium sulphite, then zinc flotation in air.

NITROGEN FLOTATION

11-201 Bulk copper, lead flotation in nitrogen with 5 g/tonne collector and 1.0 kg/tonne sodium sulphite, then zinc flotation in air.

11-202 Bulk copper, lead flotation in air with 5 g/tonne collector and 1.1 kg/tonne zinc sulphate, then zinc flotation in air.

11-203 Bulk copper, lead, pyrite flotation in air following conditioning with 5 g/tonne collector and 1.1 kg/tonne zinc sulphate, then zinc flotation in air.

11-204 Bulk copper, lead, pyrite flotation in nitrogen following conditioning with 5 g/tonne collector and 1.1 kg/tonne zinc sulphate, then zinc flotation in nitrogen.

11-205 Bulk copper, lead, pyrite flotation in nitrogen following conditioning with 5 g/tonne collector and 1.1 kg/tonne zinc sulphate, then zinc flotation in air.

COLLECTORLESS FLOTATION

11-301 Collectorless flotation followed by zinc flotation.

sample reference	SOLIDS MASS BALANCE sample weight	mass pull sample	mass pull total	COPPER MASS BALANCE copper assay (%)	copper units	copper recovery stage	copper recovery total	LEAD MASS BALANCE lead assay (%)	lead units	lead recovery stage	lead recovery total	ZINC MASS BALANCE zinc assay (%)	zinc units	zinc recovery stage	zinc recovery total	IRON MASS BALANCE iron assay (%)	iron units	iron recovery stage	iron recovery total
bulk rougher - 30 seconds	114.66	11.58%	11.58%	2.64	0.306	46.10%	46.10%	1.60	0.195	27.86%	27.86%	3.80	0.440	4.23%	4.23%	42.63	4.936	17.39%	17.39%
bulk scavenger I - 1 minutes	59.31	6.01%	17.59%	4.12	0.240	37.34%	83.44%	3.36	0.202	28.92%	56.79%	7.20	0.433	4.16%	8.40%	33.30	2.006	7.07%	24.46%
bulk scavenger II - 2.5 minutes	20.21	2.05%	20.44%	1.60	0.046	6.87%	90.31%	3.35	0.095	13.67%	70.46%	13.40	0.382	3.67%	12.07%	24.71	0.704	2.48%	26.94%
zinc rougher - time 1 minute	109.76	11.08%	31.52%	0.12	0.013	2.01%	92.31%	0.31	0.034	4.92%	75.38%	55.22	6.121	58.91%	70.98%	7.63	0.846	2.98%	29.92%
zinc rougher - time 2 minutes A	44.91	4.54%	36.06%	0.28	0.013	1.91%	94.23%	0.67	0.030	4.35%	79.73%	46.65	2.116	20.36%	91.35%	10.90	0.494	1.74%	31.66%
zinc rougher - time 2 minutes B	0.00	0.00%	36.06%	0.00	0.000	0.00%	94.23%	0.00	0.000	0.00%	79.73%	0.00	0.000	0.00%	91.35%	0.00	0.000	0.00%	31.65%
zinc scavenger - time 30 seconds	24.94	2.52%	38.58%	0.30	0.008	1.14%	95.37%	1.96	0.049	7.07%	86.80%	21.56	0.543	5.23%	96.57%	24.29	0.612	2.16%	33.81%
zinc scavenger - time 1 minute	0.00	0.00%	38.58%	0.00	0.000	0.00%	95.37%	0.00	0.000	0.00%	86.80%	0.00	0.000	0.00%	96.57%	0.00	0.000	0.00%	33.81%
zinc scavenger - time 2 minutes	0.00	0.00%	38.58%	0.00	0.000	0.00%	95.37%	0.00	0.000	0.00%	86.80%	0.00	0.000	0.00%	96.57%	0.00	0.000	0.00%	33.81%
final tails	608.20	61.42%	100.00%	0.05	0.031	4.63%	100.00%	0.15	0.092	13.20%	100.00%	0.58	0.356	3.43%	100.00%	30.59	18.709	66.19%	100.00%
reconstituted feed	990.19				0.663	100.00%			0.698	100.00%			10.391	100.00%			20.388	100.00%	

TEST SUMMARY:	sample weight	mass pull sample	mass pull total	copper assay %	copper recovery stage	copper recovery total	lead assay %	lead recovery stage	lead recovery total	zinc assay %	zinc recovery stage	zinc recovery total	iron assay %	iron recovery stage	iron recovery total
bulk flotation	202.38	20.44%	20.44%	2.93	90.31%	90.31%	2.41	70.46%	70.46%	6.14	12.07%	12.07%	37.41	26.94%	26.94%
zinc rougher flotation	154.67	15.62%	36.06%	0.17	3.92%	94.23%	0.41	9.27%	79.73%	52.73	79.27%	91.35%	0.58	4.72%	31.66%
zinc scavenger flotation time 0-1.5 min	24.94	2.52%	38.58%	0.30	1.14%	95.37%	1.96	7.07%	86.80%	21.56	5.23%	96.57%	24.29	2.16%	33.81%
final flotation tails	608.20	61.42%	100.00%	0.05	4.63%	100.00%	0.15	13.20%	100.00%	0.58	3.43%	100.00%	30.59	66.19%	100.00%

11-101 Bulk copper,lead flotation in air with 40 g/tonne collector and 3kg/tonne sodium sulphite, then zinc flotation in air.

F L O T A T I O N   C O N D I T I O N S

sample reference	pH	activator added g/t	Pre-conditioning gas	Pre-conditioning time	collector type	collector addition g/t	flotation gas
bulk rougher - 30 seconds	9.2	-	air	3 min	plant*	50	air
bulk scavenger - 1 minute	9.2	-	-	-	-	-	air
bulk scavenger - 2.5 minutes	9.2	-	-	-	-	-	air
zinc rougher - 1 minute	10.5	1100	none	5 min	KEX	30	air
zinc rougher - 2 minutes	10.5	-	-	-	-	-	air
zinc scavenger - 1 minute	10.5	-	-	-	KEX	20	air

GRINDING CONDITIONS:

20 minutes, mild steel charge

2000 g/t sodium sulphite

NOTE:

Plant xanthate contains 50% Ethyl xanthate and 50% dithiophosphate (Cyanamid 241)

11-101 Bulk copper,lead flotation in air with 40 g/tonne collector and 3kg/tonne sodium sulphite, then zinc flotation in air.

SOLIDS MASS BALANCE / COPPER MASS BALANCE

sample reference	sample weight (grams)	mass pull sample	mass pull total	copper assay (%)	copper units	copper recovery stage	copper recovery total
bulk rougher 30 seconds	294.93	29.33%	29.33%	1.03	0.302	46.10%	46.10%
bulk scavenger - 1 minutes	179.95	17.90%	47.23%	1.31	0.234	35.77%	81.88%
bulk scavenger II 2.5 minutes	40.87	4.86%	52.09%	1.57	0.076	11.64%	93.52%
zinc rougher time 1 minute	113.00	11.24%	63.32%	0.13	0.015	2.23%	95.75%
zinc rougher - time 2 minutes A	28.19	2.80%	66.13%	0.32	0.009	1.37%	97.12%
zinc rougher time 2 minutes B	0 00	0.00%	66.13%	0.00	0.000	0.00%	97.12%
zinc scavenger - time 30 seconds	48 79	4.85%	70 98%	0.15	0 007	1 11%	98.23%
zinc scavenger time 1 minute	0 00	0 00%	70 98%	0 00	0 000	0.00%	98.23%
zinc scavenger - time 2 minutes	0.00	0 00%	70.98%	0.00	0.000	0.00%	98.23%
final tails	291.80	29.02%	100.00%	0.04	0.012	1.77%	100.00%
reconstituted feed	1005.53				0.655	100.00%	

LEAD MASS BALANCE

sample reference	lead assay (%)	lead units	lead recovery stage	lead recovery total
bulk rougher 30 seconds	1.00	0.293	41.87%	41.87%
bulk scavenger - 1 minutes	1.36	0.243	34.74%	76 61%
bulk scavenger II 2.5 minutes	1.73	0.084	12.00%	88.61%
zinc rougher time 1 minute	0.16	0.018	2.57%	91 18%
zinc rougher - time 2 minutes A	0.46	0.013	1.84%	93.02%
zinc rougher time 2 minutes B	0.00	0.000	0.00%	93.02%
zinc scavenger - time 30 seconds	0.29	0.014	2 01%	95.03%
zinc scavenger time 1 minute	0 00	0.000	0 00%	95.03%
zinc scavenger - time 2 minutes	0.00	0.000	0.00%	95.03%
final tails	0.12	0.035	4.97%	100.00%
reconstituted feed		0.701	100.00%	

ZINC MASS BALANCE

sample reference	zinc assay (%)	zinc units	zinc recovery stage	zinc recovery total
bulk rougher 30 seconds	4.40	1.291	12 66%	12.66%
bulk scavenger - 1 minutes	4.66	0.834	8.18%	20.84%
bulk scavenger II 2.5 minutes	6.30	0.306	3.00%	23.84%
zinc rougher time 1 minute	55.82	6.273	61.53%	85.37%
zinc rougher - time 2 minutes A	44.34	1.243	12.19%	97.56%
zinc rougher time 2 minutes B	0 00	0 000	0 00%	97.56%
zinc scavenger - time 30 seconds	3.21	0.156	1.53%	99.09%
zinc scavenger time 1 minute	0.00	0.000	0.00%	99.09%
zinc scavenger - time 2 minutes	0.00	0.000	0.00%	99.09%
final tails	0.32	0.093	0.91%	100.00%
reconstituted feed		10.195	100.00%	

IRON MASS BALANCE

sample reference	iron assay (%)	iron units	iron recovery stage	iron recovery total
bulk rougher 30 seconds	38.03	11.389	39.75%	39.75%
bulk scavenger - 1 minutes	39.30	7.033	24.54%	64.29%
bulk scavenger II 2.5 minutes	37.97	1.845	6.44%	70.73%
zinc rougher time 1 minute	7.55	0.848	2 96%	73.69%
zinc rougher - time 2 minutes A	11.24	0.315	1.10%	74.79%
zinc rougher time 2 minutes B	0 00	0 000	0 00%	74.79%
zinc scavenger - time 30 seconds	37 75	1.932	[illegible]	81.19%
zinc scavenger time 1 minute	0.00	0.000	0.00%	81.18%
zinc scavenger - time 2 minutes	0.00	0.000	0.00%	81.18%
final tails	18.50	5.392	18.82%	100.00%
reconstituted feed		28.655	100.00%	

TEST SUMMARY:

	sample weight	mass pull sample	mass pull total	copper assay %	copper recovery stage	copper recovery total	lead assay %	lead recovery stage	lead recovery total	zinc assay %	zinc recovery stage	zinc recovery total	iron assay %	iron recovery stage	iron recovery total
bulk flotation	523.75	52.09%	52.09%	1.18	93.52%	93.52%	1.19	88.61%	88.61%	4.67	23.84%	23.84%	38.91	70.73%	70.73%
zinc rougher flotation	141.19	14.04%	66.13%	0.17	3.60%	97.12%	0.22	4.41%	93.02%	53.53	73.72%	97.56%	8.29	4.06%	74.79%
zinc scavenger flotation	48.79	4.85%	70.98%	0.15	1.11%	98.23%	0.29	2.01%	95.03%	3.21	1.53%	99.09%	37.75	6.39%	81.18%
final flotation tails	291.80	29.02%	100.00%	0.04	1.77%	100.00%	0.12	4.97%	100.00%	0.32	0.91%	100.00%	18.50	18.82%	100.00%

11-102 Bulk copper,lead flotation in air with 40 g/tonne collector and 1.5kg/tonne sodium sulphite, then zinc flotation in air

FLOTATION CONDITIONS

sample reference	pH	activator added g/t	Pre-conditioning gas	Pre-conditioning time	collector type	collector addition g/t	flotation gas
bulk rougher - 30 seconds	9.5	-	air	3 min	plant*	40	air
bulk scavenger - 1 minute	9.5	-	-	-	-	-	air
bulk scavenger - 2.5 minutes	9.5	-	-	-	-	-	air
zinc rougher - 1 minute	.5	1100	none	5 min	KEX	30	air
zinc rougher - 2 minutes	10.5	-	-	-	-	-	air
zinc scavenger - 2 minutes	10.5	-	-	-	KEX	20	air

GRINDINE CONDITIONS:

20 minutes, mild steel charge

1600 g/t sodium sulphite

NOTE:

Plant xanthate contains 50% Ethyl xanthate and

50% dithiophosphate (Cyanamid 241)

11-102 Bulk copper,lead flotation in air with 40 g/tonne collector and 1.5kg/tonne sodium sulphite, then zinc flotation in air

	SOLIDS MASS BALANCE			COPPER MASS BALANCE				LEAD MASS BALANCE				ZINC MASS BALANCE				IRON MASS BALANCE			
	sample weight	mass pull		copper assay		copper recovery		lead assay		lead recovery		zinc assay		zinc recovery		iron assay		iron recovery	
sample reference	(grams)	sample	total	(%)	units	stage	total	(%)	units	stage	total	(%)	units	stage	total	(%)	units	stage	total
bulk rougher 1 minute	25.43	2.42%	2.42%	9.00	0.218	31.42%	31.42%	8.58	0.208	27.25%	27.25%	9.57	0.231	2.30%	2.30%	26.99	0.653	2.15%	2.15%
bulk scavenger - 3 minutes	40.37	3.84%	6.26%	7.04	0.270	39.02%	70.44%	5.66	0.217	28.54%	55.79%	12.92	0.496	4.93%	7.24%	25.99	0.998	3.29%	5.43%
bulk scavenger II - 3 minutes	0.00	0.00%	6.26%	0.00	0.000	0.00%	70.44%	0.00	0.000	0.00%	55.79%	0.00	0.000	0.00%	7.24%	0.00	0.000	0.00%	5.43%
zinc rougher - time 1 minute	107.16	10.19%	16.45%	0.38	0.039	5.59%	76.03%	1.04	0.106	13.92%	69.71%	52.89	5.391	53.62%	60.86%	8.66	0.883	2.91%	8.34%
zinc rougher - time 2 minutes A	46.52	4.42%	20.88%	0.53	0.023	3.38%	79.41%	0.83	0.037	4.82%	74.54%	47.91	2.120	21.09%	81.94%	11.42	0.505	1.66%	10.00%
zinc rougher - time 2 minutes B	0.00	0.00%	20.88%	0.00	0.000	0.00%	79.41%	0.00	0.000	0.00%	74.54%	0.00	0.000	0.00%	81.94%	0.00	0.000	0.00%	10.00%
zinc scavenger - time 30 seconds	71.65	6.82%	27.69%	0.82	0.056	8.07%	87.48%	1.36	0.093	12.17%	86.71%	23.24	1.584	15.75%	97.70%	26.71	1.820	5.99%	16.00%
zinc scavenger - time 1 minute	0.00	0.00%	27.69%	0.00	0.000	0.00%	87.48%	0.00	0.000	0.00%	86.71%	0.00	0.000	0.00%	97.70%	0.00	0.000	0.00%	16.00%
zinc scavenger - time 2 minutes	0.00	0.00%	27.69%	0.00	0.000	0.00%	87.48%	0.00	0.000	0.00%	86.71%	0.00	0.000	0.00%	97.70%	0.00	0.000	0.00%	16.00%
final tails	760.20	72.31%	100.00%	0.12	0.087	12.52%	100.00%	0.14	0.101	13.29%	100.00%	0.32	6.231	2.30%	100.00%	35.29	25.518	84.00%	100.00%
reconstituted feed	1051.33				0.693	100.00%			0.762	100.00%			10.054	100.00%			30.377	100.00%	

TEST SUMMARY:	sample weight	mass pull sample	mass pull total	copper assay %	copper recovery stage	copper recovery total	lead assay %	lead recovery stage	lead recovery total	zinc assay %	zinc recovery stage	zinc recovery total	iron assay %	iron recovery stage	iron recovery total
bulk flotation	65.80	6.26%	6.26%	7.80	70.44%	70.44%	6.79	55.79%	55.79%	11.63	7.24%	7.24%	26.38	5.43%	5.43%
zinc rougher flotation	153.68	14.62%	20.88%	0.43	8.97%	79.41%	0.98	18.74%	74.54%	51.38	74.71%	81.94%	9.50	4.57%	10.00%
zinc scavenger flotation	71.65	6.82%	27.69%	0.82	8.07%	87.48%	1.36	12.17%	86.71%	23.24	15.75%	97.70%	26.71	5.99%	16.00%
final flotation tails	760.20	72.31%	100.00%	0.12	12.52%	100.00%	0.14	13.29%	100.00%	0.32	2.30%	100.00%	35.29	84.00%	100.00%

11-103 Bulk copper, lead flotation in air using 5 g/tonne collector and 1.5kg/tonne sulphite depression of pyrite, then zinc flotation in air.

FLOTATION CONDITIONS

sample reference	pH	activator added g/t	Pre-conditioning gas	Pre-conditioning time	collector type	collector addition g/t	flotation gas
bulk rougher - 1 minute	9.5	-	air	3 min	plant*	5	air
bulk scavenger - 3 minutes	9.5	-	-	-	-	-	air
zinc rougher - 1 minute	10.5	1100	none	5 min	KEX	40	air
zinc rougher - 2 minutes	10.5	-	-	-	-	-	air
zinc scavenger - 2 minutes	10.5	-	-	-	KEX	20	air

GRINDING CONDITIONS:

20 minutes, mild steel charge

1600 g/t sodium sulphite

NOTE:

Plant xanthate contains 50% Ethyl xanthate and 50% dithiophosphate (Cyanamid 241)

11-103 Bulk copper,lead flotation in air using 5 g/tonne collector and 1.5kg/tonne sulphite depression of pyrite, then zinc flotation in air.

sample reference	SOLIDS MASS BALANCE: sample weight (grams)	mass pull: sample	mass pull: total	COPPER MASS BALANCE: copper assay (%)	copper units	copper recovery: stage	copper recovery: total	LEAD MASS BALANCE: lead assay (%)	lead units	lead recovery: stage	lead recovery: total	ZINC MASS BALANCE: zinc assay (%)	zinc units	zinc recovery: stage	zinc recovery: total	IRON MASS BALANCE: iron assay (%)	iron units	iron recovery: stage	iron recovery: total
bulk rougher 1 minute	61.05	6.03%	6.03%	8.28	0.500	70.63%	70.67%	7.28	0.439	58.66%	58.66%	9.29	0.561	5.47%	5.47%	29.15	1.759	5.61%	5.61%
bulk scavenger - 3 minutes	58.90	5.82%	11.86%	2.12	0.123	17.45%	88.08%	2.23	0.130	17.34%	76.00%	14.00	0.815	7.96%	13.43%	28.78	1.652	5.27%	10.88%
bulk scavenger II - 2.5 minutes	0.00	0.00%	11.86%	0.00	0.000	0.00%	88.08%	0.00	0.000	0.00%	76.00%	0.00	0.000	0.00%	13.43%	0.00	0.000	0.00%	10.88%
zinc rougher - time 1 minute	117.06	11.57%	23.43%	0.18	0.021	2.94%	91.03%	0.46	0.053	7.11%	83.11%	55.69	6.444	62.93%	76.36%	8.12	0.940	3.00%	13.87%
zinc rougher - time 2 minutes A	46.64	4.61%	28.04%	0.29	0.013	1.89%	92.92%	0.45	0.021	2.77%	85.88%	43.23	1.993	19.46%	95.82%	13.54	0.624	1.99%	15.86%
zinc rougher - time 2 minutes B	0.00	0.00%	28.04%	0.00	0.000	0.00%	92.92%	0.00	0.000	0.00%	85.88%	0.00	0.000	0.00%	95.82%	0.00	0.000	0.00%	15.86%
zinc scavenger - time 30 seconds	35.05	3.46%	31.50%	0.26	0.009	1.27%	94.19%	0.68	0.024	3.15%	89.02%	7.80	0.270	2.64%	98.46%	39.08	1.354	4.32%	20.18%
zinc scavenger - time 1 minute	0.00	0.00%	31.50%	0.00	0.000	0.00%	94.19%	0.00	0.000	0.00%	89.02%	0.00	0.000	0.00%	98.46%	0.00	0.000	0.00%	20.18%
zinc scavenger - time 2 minutes	0.00	0.00%	31.50%	0.00	0.000	0.00%	94.19%	0.00	0.000	0.00%	89.02%	0.00	0.000	0.00%	98.46%	0.00	0.000	0.00%	20.18%
final tails	692.90	68.50%	100.00%	0.06	0.041	5.81%	100.00%	0.12	0.082	10.98%	100.00%	0.23	0.158	1.54%	100.00%	36.55	25.035	79.82%	100.00%
reconstituted feed	1011.60				0.707	100.00%			0.749	100.00%			10.241	100.00%			31.365	100.00%	

TEST SUMMARY:	sample weight	mass pull: sample	mass pull: total	copper assay %	copper recovery: stage	copper recovery: total	lead assay %	lead recovery: stage	lead recovery: total	zinc assay %	zinc recovery: stage	zinc recovery: total	iron assay %	iron recovery: stage	iron recovery: total
bulk flotation	119.95	11.86%	11.86%	5.26	88.08%	88.08%	4.80	76.00%	76.00%	11.60	13.43%	13.43%	28.77	10.83%	10.88%
zinc rougher flotation	163.70	16.18%	28.04%	0.21	4.83%	92.92%	0.46	9.88%	85.88%	52.14	82.39%	95.82%	9.66	4.99%	15.86%
zinc scavenger flotation	35.05	3.46%	31.50%	0.26	1.27%	94.19%	0.68	3.15%	89.02%	7.80	2.64%	98.46%	39.08	4.32%	20.18%
final flotation tails	692.90	68.50%	100.00%	0.06	5.81%	100.00%	0.12	10.98%	100.00%	0.23	1.54%	100.00%	36.55	79.82%	100.00%

11-104 Bulk copper,lead flotation in air using 5 g/tonne collector and 1.0kg/tonne sulphite depression of pyrite, then zinc flotation in air.

F L O T A T I O N   C O N D I T I O N S

sample reference	pH	activator added g/t	Pre-conditioning gas	Pre-conditioning time	collector type	collector addition g/t	flotation gas
bulk rougher - 1 minute	9.5	-	air	3 min	plant*	5	air
bulk scavenger - 3 minutes	9.5	-	-	-	-	-	air
zinc rougher - 1 minute	10.5	1100	none	5 min	KEX	35	air
zinc rougher - 2 minutes	10.5	-	-	-	-	-	air
zinc scavenger - 2 minutes	10.5	-	-	-	KEX	20	air

GRINDING CONDITIONS:

20 minutes, mild steel charge

1000 g/t sodium sulphite

NOTE:

Plant xanthate contains 50% Ethyl xanthate and 50% dithiophosphate (Cyanamid 241)

11-104 Bulk copper, lead flotation in air using 5 g/tonne collector and 1.0kg/tonne sulphite depression of pyrite, then zinc flotation in air.

sample reference	SOLIDS MASS BALANCE sample weight (grams)	mass pull sample	mass pull total	COPPER MASS BALANCE copper assay (%)	copper units	copper recovery stage	copper recovery total	LEAD MASS BALANCE lead assay (%)	lead units	lead recovery stage	lead recovery total	ZINC MASS BALANCE zinc assay (%)	zinc units	zinc recovery stage	zinc recovery total	IRON MASS BALANCE iron assay (%)	iron units	iron recovery stage	iron recovery total
bulk rougher 1 minute	97.71	9.72%	9.72%	2.64	0.257	39.07%	39.07%	2.64	0.257	42.52%	42.52%	5.39	0.524	5.11%	5.11%	38.09	3.703	11.94%	11.94%
bulk scavenger - 3 minutes	61 38	6 11%	15 83%	1.58	0.096	14.69%	53.76%	1.58	0.096	15.98%	58.50%	7.09	0.433	4.23%	9.34%	37.82	2.310	7.45%	19.39%
bulk scavenger II - 3 minutes	0.00	0.00%	15.83%	0.00	0.000	0.00%	53.76%	0.00	0.000	0.00%	58.50%	0.00	0.000	0.00%	9.34%	0.00	0.000	0.00%	19.39%
zinc rougher - time 1 minute	52.78	5 25%	21.08%	0.94	0.049	7.51%	61.27%	0.94	0.049	8.18%	66.68%	49.61	2.605	25.43%	34.77%	9.34	0.490	1.58%	20.97%
zinc rougher - time 2 minutes A	29.36	2.92%	24.00%	1.02	0.030	4.54%	65.81%	1.02	0.030	4.94%	71.61%	43.53	1.272	12.41%	47.18%	11.10	0.324	1.05%	22.02%
zinc rougher - time 2 minutes B	0.00	0.00%	24.00%	0.00	0.000	0.00%	65.81%	0.00	0.000	0.00%	71.61%	0.00	0.000	0.00%	47.18%	0.00	0.000	0.00%	22.02%
zinc scavenger - time 2 minutes	148.43	14.77%	38.77%	0 42	0.062	9.44%	75.25%	0.42	0 062	10.28%	81.89%	34.27	5.061	49.40%	96.59%	22.70	3.352	10.81%	32.83%
zinc scavenger - time 2 minutes	20.36	2 03%	40.79%	0.72	0.015	2.22%	77.47%	0.72	0.015	2.42%	84.31%	7.32	0.148	1.45%	98.03%	36.06	0.730	2.36%	35.19%
zinc scavenger - time 2 minutes	0.00	0.00%	40.79%	0.00	0.000	0.00%	77.47%	0.00	0.000	0.00%	84.31%	0.00	0.000	0.00%	98.03%	0.00	0.000	0.00%	35.19%
final tails	595.10	59.21%	100.00%	0.25	0.148	22.53%	100.00%	0.16	0.095	15.69%	100.00%	0.34	0.201	1.97%	100.00%	33.94	20.095	64.81%	100.00%
reconstituted feed	1005.12				0.657	100.00%			0.604	100.00%			10.244	100.00%			31.005	100.00%	

TEST SUMMARY:	sample weight	mass pull sample	mass pull total	copper assay %	copper recovery stage	copper recovery total	lead assay %	lead recovery stage	lead recovery total	zinc assay %	zinc recovery stage	zinc recovery total	iron assay %	iron recovery stage	iron recovery total
bulk flotation	159.09	15.83%	15.83%	2.23	53.76%	53.76%	2.23	58.50%	58.50%	6.05	9.34%	9.34%	37.99	19.39%	19.39%
zinc rougher flotation	82.14	8.17%	24.00%	0.97	12.05%	65.81%	0.97	13.11%	71.61%	47.44	37.84%	47.18%	9.97	2.63%	22.02%
zinc scavenger flotation	168.79	16.79%	40.79%	0.46	11.66%	77.47%	0.46	12.69%	84.31%	31.02	50.85%	98.03%	24.31	13.17%	35.19%
final flotation tails	595.10	59.21%	100.00%	0.25	22.53%	100.00%	0.16	15.69%	100.00%	0.34	1.97%	100.00%	33.94	64.81%	100.00%

11-201 Bulk copper,lead flotation in nitrogen with 5 g/t collector and 1.0 kg/tonne sulphite depression of pyrite, then zinc flotation in air.

FLOTATION CONDITIONS

sample reference	pH	activator added g/t	Pre-conditioning gas	Pre-conditioning time	collector type	collector addition g/t	flotation gas
bulk rougher - 1 minute	9.5	-	nitrogen	20 min	plant*	5	nitrogen
bulk scavenger - 3 minutes	9.5	-	-	-	-	-	nitrogen
zinc rougher - 1 minute	10.5	1100	none	5 min	KEX	35	air
zinc rougher - 2 minutes	10.5	-	-	-	-	-	air
zinc scavenger - 2 minutes A	10.5	-	-	-	KEX	20	air
zinc scavenger - 2 minutes B	10.5	-	-	-	-	-	air

GRINDING CONDITIONS:

20 minutes, mild steel charge

1000 g/t sodium sulphite

NOTE:

Plant xanthate contains 50% Ethyl xanthate and 50% dithiophosphate (Cyanamid 241)

11-201 Bulk copper, lead flotation in nitrogen with 5 g/t collector and 1.0 kg/tonne sulphite depression of pyrite, then zinc flotation in air.

test number 77	SOLIDS MASS BALANCE			COPPER MASS BALANCE				LEAD MASS BALANCE				ZINC MASS BALANCE				IRON MASS BALANCE			
	sample weight (grams)	mass pull sample	mass pull total	copper assay (%)	copper units	copper recovery stage	copper recovery total	lead assay (%)	lead units	lead recovery stage	lead recovery total	zinc assay (%)	zinc units	zinc recovery stage	zinc recovery total	iron assay (%)	iron units	iron recovery stage	iron recovery total
sample reference																			
bulk rougher 1 minute	143.95	13.95%	13.95%	2.39	0.334	48.72%	48.72%	1.48	0.207	27.81%	27.81%	3.02	0.421	4.17%	4.17%	41.78	5.830	19.54%	19.54%
bulk scavenger - 3 minutes	152.67	14.80%	28.76%	1.35	0.200	29.19%	77.91%	1.62	0.240	32.29%	60.10%	4.71	0.697	6.90%	11.07%	40.39	5.978	20.03%	39.57%
bulk scavenger II - 3 minutes	0.00	0.00%	28.76%	0.00	0.000	0.00%	77.91%	0.00	0.000	0.00%	60.10%	0.00	0.000	0.00%	11.07%	0.00	0.000	0.00%	39.57%
zinc rougher time 2 minutes A	115.20	11.17%	39.92%	0.80	0.089	13.05%	90.96%	1.65	0.184	24.82%	84.92%	28.92	3.230	31.97%	43.04%	24.46	2.732	9.15%	48.73%
zinc rougher time 2 minutes B	72.19	7.00%	46.92%	0.25	0.017	2.56%	93.52%	0.42	0.029	3.96%	88.88%	30.28	2.119	20.98%	64.02%	22.79	1.595	5.35%	54.07%
zinc rougher - time 2 minutes C	0.00	0.00%	46.92%	0.00	0.000	0.00%	93.52%	0.00	0.000	0.00%	88.88%	0.00	0.000	0.00%	64.02%	0.00	0.000	0.00%	54.07%
zinc scavenger - time 2 minutes A	192.00	18.69%	65.61%	0.10	0.019	2.73%	96.25%	0.19	0.036	4.78%	93.66%	16.16	3.020	29.90%	93.92%	35.11	6.562	21.99%	76.07%
zinc scavenger - time 2 minutes B	82.26	7.97%	73.59%	0.09	0.007	1.05%	97.30%	0.16	0.013	1.72%	95.38%	5.95	0.474	4.70%	98.61%	38.74	3.089	10.35%	86.42%
zinc scavenger - time 2 minutes C	0.00	0.00%	73.59%	0.00	0.000	0.00%	97.30%	0.00	0.000	0.00%	95.38%	0.00	0.000	0.00%	98.61%	0.00	0.000	0.00%	86.42%
final tails	272.46	26.41%	100.00%	0.07	0.018	2.70%	100.00%	0.13	0.034	4.62%	100.00%	0.53	0.140	1.39%	100.00%	15.34	4.052	13.58%	100.00%
reconstituted feed	1031.53				0.685	100.00%			0.743	100.00%			10.107	100.00%			29.838	100.00%	

TEST SUMMARY:	sample weight	mass pull sample	mass pull total	copper assay %	copper recovery stage	copper recovery total	lead assay %	lead recovery stage	lead recovery total	zinc assay %	zinc recovery stage	zinc recovery total	iron assay %	iron recovery stage	iron recovery total
bulk flotation	296.62	28.76%	28.76%	1.85	77.91%	77.91%	1.55	60.10%	60.10%	3.89	11.07%	11.07%	41.06	39.57%	39.57%
zinc rougher flotation	187.39	18.17%	46.92%	0.59	15.61%	93.52%	1.18	28.77%	88.88%	29.44	52.95%	64.02%	23.82	14.50%	54.07%
zinc scavenger flotation	275.06	26.67%	73.59%	0.10	3.78%	97.30%	0.18	6.50%	95.38%	13.11	34.60%	98.61%	36.20	32.35%	86.42%
final flotation tails	272.46	26.41%	100.00%	0.07	2.70%	100.00%	0.13	4.62%	100.00%	0.53	1.39%	100.00%	15.34	13.58%	100.00%

11-202 Bulk copper, lead, pyrite flotation in air following conditioning in nitrogen with 5 g/t collector and zinc sulphate depression of sphalerite. Zinc flotation in air.

FLOTATION CONDITIONS

sample reference	pH	activator added g/t	Pre-conditioning gas	Pre-conditioning time	collector type	collector addition g/t	flotation gas
bulk rougher - 1 minute	9.5	-	nitrogen	15 sec	plant*	5	air
bulk scavenger - 3 minutes	9.5	-	-	-	-	-	air
zinc rougher - 1 minute	10.5	1100	none	5 min	KEX	35	air
zinc rougher - 2 minutes	10.5	-	-	-	-	-	air
zinc scavenger - 2 minutes A	10.5	-	-	-	KEX	20	air
zinc scavenger - 2 minutes B	10.5	-	-	-	-	-	air

GRINDING CONDITIONS:

20 minutes, mild steel charge

1100 g/t zinc sulphate

NOTE:

Plant xanthate contains 50% ethyl xanthate and 50% dithiophosphate (Cyanamid 241)

11-202 Bulk copper,lead, pyrite flotation in air following conditioning in nitrogen with 5 g/t collector and zinc sulphate depression of sphalerite. Zinc flotation in air.

	SOLIDS MASS BALANCE			COPPER MASS BALANCE				LEAD MASS BALANCE				ZINC MASS BALANCE				IRON MASS BALANCE			
	sample	mass pull		copper		copper		lead		lead		zinc		zinc		iron		iron	
	weight	sample	total	assay	units	recovery		assay	units	recovery		assay	units	recovery		assay	units	recovery	
sample reference	(grams)			(%)		stage	total	(%)		stage	total	(%)		stage	total	(%)		stage	total
bulk rougher - 1 minute	213.30	20.96%	20.96%	2.20	0.461	65.77%	65.77%	1.69	0.354	46.03%	46.03%	3.60	0.755	7.32%	7.32%	41.38	8.674	28.22%	28.22%
bulk scavenger - 3 minutes	48.64	4.78%	25.74%	2.68	0.128	18.27%	84.04%	2.52	0.120	15.92%	62.75%	9.88	0.472	4.58%	11.90%	35.15	1.680	5.47%	33.69%
bulk scavenger II - 3 minutes	0.00	0.00%	25.74%	0.00	0.000	0.00%	84.04%	0.00	0.000	0.00%	62.75%	0.00	0.000	0.00%	11.90%	0.00	0.000	0.00%	33.69%
zinc rougher time 1 minute	133.33	13.10%	38.84%	0.45	0.059	8.41%	92.45%	1.38	0.181	23.90%	86.65%	41.04	5.377	52.14%	64.04%	16.97	2.224	7.23%	40.92%
zinc rougher - time 2 minutes A	53.71	5.28%	44.12%	0.21	0.011	1.59%	94.03%	0.41	0.022	2.86%	89.51%	36.26	1.914	18.56%	82.60%	19.00	1.003	3.26%	44.19%
zinc rougher time 2 minutes B	0.00	0.00%	44.12%	0.00	0.000	0.00%	94.03%	0.00	0.000	0.00%	89.51%	0.00	0.000	0.00%	82.60%	0.00	0.000	0.00%	44.19%
zinc scavenger time 2 minutes A	62.85	6.18%	50.30%	0.09	0.006	0.79%	94.82%	0.22	0.014	1.80%	91.30%	21.20	1.309	12.70%	95.29%	30.37	1.876	6.10%	50.29%
zinc scavenger time 2 minutes B	31.25	3.07%	53.37%	0.12	0.004	0.53%	95.34%	0.32	0.010	1.30%	92.60%	10.95	0.336	3.26%	98.55%	34.23	1.051	3.42%	53.71%
zinc scavenger - time 2 minutes C	0.00	0.00%	53.37%	0.00	0.000	0.00%	95.34%	0.00	0.000	0.00%	92.60%	0.00	0.000	0.00%	98.55%	0.00	0.000	0.00%	53.71%
final tails	474.50	46.63%	100.00%	0.07	0.033	4.66%	100.00%	0.12	0.056	7.40%	100.00%	0.32	0.149	1.45%	100.00%	30.51	14.227	46.29%	100.00%
reconstituted feed	1017.58				0.701	100.00%			0.757	100.00%			10.313	100.00%			30.734	100.00%	

TEST SUMMARY:	sample	mass pull		copper	recovery		lead	recovery		zinc	recovery		iron	recovery	
	weight	sample	total	assay %	stage	total	assay %	stage	total	assay %	stage	total	assay %	stage	total
bulk flotation	261.94	25.74%	25.74%	2.29	84.04%	84.04%	1.84	62.75%	62.75%	4.77	11.90%	11.90%	40.22	33.69%	33.69%
zinc rougher flotation	187.04	18.38%	44.12%	0.38	9.99%	94.03%	1.10	26.76%	89.51%	39.67	70.70%	82.60%	17.55	10.50%	44.19%
zinc scavenger flotation	94.10	9.25%	53.37%	0.10	1.32%	95.34%	0.25	3.10%	92.60%	17.80	15.96%	98.55%	31.65	9.52%	53.71%
final flotation tails	474.50	46.63%	100.00%	0.07	4.66%	100.00%	0.12	7.40%	100.00%	0.32	1.45%	100.00%	30.51	46.29%	100.00%

11-203 Bulk copper,lead, pyrite flotation in air following conditioning with 5 g/t collector and zinc sulphate depression of sphalerite. Zinc flotation in air.

F L O T A T I O N   C O N D I T I O N S

sample reference	pH	activator added g/t	Pre-conditioning gas	Pre-conditioning time	collector type	collector addition g/t	flotation gas
bulk rougher - 1 minute	9.5	-	air	3 min	plant*	5	air
bulk scavenger - 3 minutes	9.5	-	-	-	-	-	air
zinc rougher - 1 minute	10.5	1100	none	5 min	KEX	35	air
zinc rougher - 2 minutes	10.5	-	-	-	-	-	air
zinc scavenger - 2 minutes A	10.5	-	-	-	KEX	20	air
zinc scavenger - 2 minutes B	10.5	-	-	-	-	-	air

GRINDING CONDITIONS:

20 minutes, mild steel charge

1100 g/t zinc sulphate

NOTE:

Plant xanthate contains 50% ethyl xanthate and 50% dithiophosphate (Cyanamid 241)

11-203 Bulk copper,lead, pyrite flotation in air following conditioning with 5 g/t collector and zinc sulphate depression of sphalerite. Zinc flotation in air.

sample reference	SOLIDS MASS BALANCE sample weight (grams)	mass pull sample	mass pull total	COPPER MASS BALANCE copper assay (%)	copper units	copper recovery stage	copper recovery total
bulk rougher 1 minute	463.30	42.42%	42.42%	0.45	0.191	28.57%	28.57%
bulk scavenger - 3 minutes	150 36	13.77%	56.18%	1.18	0.162	24.32%	52.89%
bulk scavenger II - 2.5 minutes	0.00	0.00%	56.18%	0.00	0.000	0.00%	52.89%
zinc rougher - time 1 minute	98.67	9.03%	65.22%	2.65	0.239	35.83%	88.72%
zinc rougher - time 2 minutes A	29.69	2.71%	67.93%	0.72	0.020	2.92%	91.65%
zinc rougher - time 2 minutes B	0.00	0.00%	67.93%	0.00	0.000	0.00%	91.65%
zinc scavenger - time 2 minutes a	72 32	6.62%	74.55%	0.42	0.028	4.16%	95.81%
zinc scavenger - time 2 minutes b	0 00	0.00%	74.55%	0 00	0 000	0.00%	95 81%
zinc scavenger - time 2 minutes c	0.00	0.00%	74.55%	0.00	0.000	0.00%	95.81%
final tails	277.97	25.45%	100.00%	0.11	0.028	4.19%	100.00%
reconstituted feed	1097.26				0.668	100.00%	

sample reference	LEAD MASS BALANCE lead assay (%)	lead units	lead recovery stage	lead recovery total	ZINC MASS BALANCE zinc assay (%)	zinc units	zinc recovery stage	zinc recovery total	IRON MASS BALANCE iron assay (%)	iron units	iron recovery stage	iron recovery total
bulk rougher 1 minute	0.56	0.238	34.44%	34.44%	1.61	0.683	6.72%	6.72%	45.22	19.181	64.63%	64.63%
bulk scavenger - 3 minutes	1.34	0.184	26.75%	61.19%	3.83	0.527	5.19%	11.91%	41.23	5.676	19.13%	83.76%
bulk scavenger II - 2.5 minutes	0.00	0.000	0.00%	61.19%	0.00	0.000	0.00%	11.91%	0.00	0.000	0.00%	83.76%
zinc rougher - time 1 minute	2.23	0.201	29.21%	90.40%	37.28	3.368	33.14%	45.05%	15.12	1.366	4.60%	88.36%
zinc rougher - time 2 minutes A	0.54	0.015	2.12%	92.53%	43.13	1.170	11.52%	56.57%	11.67	0.317	1.07%	89.43%
zinc rougher - time 2 minutes B	0.00	0.000	0.00%	92.53%	0.00	0.000	0.00%	56.57%	0.00	0.000	0.00%	89.43%
zinc scavenger - time 2 minutes a	0.24	0 016	2 30%	94.83%	50.58	3.349	32.96%	89.53%	9.14	0.605	2.04%	91.47%
zinc scavenger - time 2 minutes b	0 00	0.000	0.00%	94 83%	0.00	0.000	0.00%	89.53%	0.00	0.000	0 00%	91 47%
zinc scavenger - time 2 minutes c	0.00	0.000	0.00%	94 83%	0.00	0.000	0.00%	89.53%	0.00	0.000	0.00%	91.47%
final tails	0.14	0.036	5.17%	100.00%	4.18	1.064	10.47%	100.00%	9.95	2.532	8.53%	100.00%
reconstituted feed		0.690	100.00%			10.161	100.00%			29.676	100.00%	

TEST SUMMARY:	sample weight	mass pull sample	mass pull total	copper assay %	recovery stage	recovery total	lead assay %	recovery stage	recovery total	zinc assay %	recovery stage	recovery total	iron assay %	recovery stage	recovery total
bulk flotation	613.66	56.18%	56.18%	0.63	52.89%	52.89%	0.75	61.19%	61.19%	2.15	11.91%	11.91%	44.24	83.76%	83.76%
zinc rougher flotation	128.31	11.75%	67.93%	2.20	38.76%	91.65%	1.04	31.34%	92.53%	38.63	44.66%	56.57%	14.32	5.67%	89.43%
zinc scavenger flotation	72.32	6.62%	74.55%	0.42	4.16%	95.81%	0.24	2.30%	94.83%	50.58	32.96%	89.53%	9.14	2.04%	91.47%
final flotation tails	277.97	25.45%	100.00%	0.11	4.19%	100.00%	0.14	5.17%	100.00%	4.18	10.47%	100.00%	9.95	8.53%	100.00%

11-204 Bulk copper,lead,pyrite flotation in nitrogen following nitrogen conditioning, 5 g/t collector and zinc sulphate depression. Zinc flotation in nitrogen.

FLOTATION CONDITIONS

sample reference	pH	activator added g/t	Pre-conditioning gas	Pre-conditioning time	collector type	collector addition g/t	flotation gas
bulk rougher - 1 minute	9.5	-	nitrogen	20 min	-	-	nitrogen
bulk scavenger - 3 minutes	9.5	-	-	-	-	-	nitrogen
zinc rougher - 1 minute	10.5	1100	none	5 min	KEX	35	air
zinc rougher - 2 minutes	10.5	-	-	-	-	-	air
zinc scavenger - 2 minutes	10.5	-	-	-	KEX	20	air

GRINDING CONDITIONS:

20 minutes, mild steel charge

1100 g/t zinc sulphate

NOTE:

Plant xanthate contains 50% ethyl xanthate and

50% dithiophosphate (Cyanamid 241)

11-204 Bulk copper,lead,pyrite flotation in nitrogen following nitrogen conditioning, 5 g/t collector and zinc sulphate depression. Zinc flotation in nitrogen.

sample reference	SOLIDS MASS BALANCE sample weight (grams)	mass pull sample	mass pull total	COPPER MASS BALANCE copper assay (%)	copper units	copper recovery stage	copper recovery total	LEAD MASS BALANCE lead assay (%)	lead units	lead recovery stage	lead recovery total	ZINC MASS BALANCE zinc assay (%)	zinc units	zinc recovery stage	zinc recovery total	IRON MASS BALANCE iron assay (%)	iron units	iron recovery stage	iron recovery total
bulk rougher 30 seconds	176.55	17.73%	17.73%	1.73	0.307	45.22%	45.22%	1.14	0.202	28.74%	28.74%	3.21	0.569	5.55%	5.55%	40.46	7.173	24.99%	24.99%
bulk scavenger 1 minutes	68.02	6.83%	24.56%	3.03	0.207	30.51%	75.73%	2.18	0.149	21.18%	49.92%	7.78	0.531	5.18%	10.73%	35.44	2.421	8.43%	33.42%
bulk scavenger II - 2.5 minutes	0.00	0.00%	24.56%	0.00	0.000	0.00%	75.73%	0.00	0.000	0.00%	49.92%	0.00	0.000	0.00%	10.73%	0.00	0.000	0.00%	33.42%
zinc circuit																			
zinc rougher time 1 minute	168.50	16.92%	41.48%	0.70	0.118	17.46%	93.19%	1.45	0.245	34.89%	84.81%	47.76	8.081	78.82%	89.55%	11.76	1.990	6.93%	40.35%
zinc rougher - time 2 minutes A	21.94	2.20%	43.68%	0.42	0.009	1.36%	94.56%	0.84	0.019	2.63%	87.44%	35.27	0.777	7.58%	97.13%	18.24	0.402	1.40%	41.75%
zinc rougher time 2 minutes B	0.00	0.00%	43.68%	0.00	0.000	0.00%	94.56%	0.00	0.000	0.00%	87.44%	0.00	0.000	0.00%	97.13%	0.00	0.000	0.00%	41.75%
zinc scavenger time 30 seconds	108.68	10.91%	54.60%	0.08	0.009	1.29%	95.85%	0.28	0.031	4.35%	91.78%	1.54	0.168	1.64%	98.77%	44.24	4.828	16.82%	58.57%
zinc scavenger - time 1 minute	23.42	2.35%	56.95%	0.10	0.002	0.35%	96.19%	0.26	0.006	0.87%	92.65%	1.17	0.028	0.27%	99.03%	43.16	1.015	3.54%	62.11%
zinc scavenger - time 2 minutes	0.00	0.00%	56.95%	0.00	0.000	0.00%	96.19%	0.00	0.000	0.00%	92.65%	0.00	0.000	0.00%	99.03%	0.00	0.000	0.00%	62.11%
final tails	428.70	43.05%	100.00%	0.06	0.026	3.81%	100.00%	0.12	0.052	7.35%	100.00%	0.23	0.099	0.97%	100.00%	25.27	10.879	37.89%	100.00%
reconstituted feed	995.81				0.678	100.00%			0.703	100.00%			10.254	100.00%			28.708	100.00%	

TEST SUMMARY:	sample weight	mass pull sample	mass pull total	copper assay %	recovery stage	recovery total	lead assay %	recovery stage	recovery total	zinc assay %	recovery stage	recovery total	iron assay %	recovery stage	recovery total
bulk flotation	244.57	24.56%	24.56%	2.09	75.73%	75.73%	1.43	49.92%	49.92%	4.48	10.73%	10.73%	39.06	33.42%	33.42%
zinc rougher flotation	190.44	19.12%	43.68%	0.67	18.83%	94.56%	1.38	37.52%	87.44%	46.32	86.39%	97.13%	12.51	8.33%	41.75%
zinc scavenger flotation	132.10	13.27%	56.95%	0.08	1.63%	96.19%	0.28	5.22%	92.65%	1.47	1.91%	99.03%	44.05	20.35%	62.11%
final flotation tails	428.70	43.05%	100.00%	0.06	3.81%	100.00%	0.12	7.35%	100.00%	0.23	0.97%	100.00%	25.27	37.89%	100.00%

11-205 Bulk copper,lead,pyrite flotation in air following 5 g/t collector addition and zinc sulphate depression. Then zinc flotation in air.

F L O T A T I O N   C O N D I T I O N S

sample reference	pH	activator added g/t	Pre-conditioning gas	Pre-conditioning time	collector type	collector addition g/t	flotation gas
bulk rougher - 1 minute	9.5	-	air	3 min	-	-	air
bulk scavenger - 3 minutes	9.5	-	-	-	-	-	air
zinc rougher - 1 minute	10.5	1100	none	5 min	KEX	35	air
zinc rougher - 2 minutes	10.5	-	-	-	-	-	air
zinc scavenger - 2 minutes A	10.5	-	-	-	KEX	20	air
zinc scavenger - 2 minutes B	10.5	-	-	-	-	-	air

GRINDING CONDITIONS:

20 minutes, mild steel charge

1100 g/t zinc sulphate

NOTE:

Plant xanthate contains 50% ethyl xanthate and 50% dithiophosphate (Cyanamid 241)

11-205 Bulk copper,lead,pyrite flotation in air following 5 g/t collector addition and zinc sulphate depression. Then zinc flotation in air.

sample reference	SOLIDS MASS BALANCE sample weight (grams)	mass pull sample	mass pull total	COPPER MASS BALANCE copper assay (%)	copper units	copper recovery stage	copper recovery total	LEAD MASS BALANCE lead assay (%)	lead units	lead recovery stage	lead recovery total
collectorless rougher - 1 minute	58.50	5.65%	5.65%	7.52	0.425	67.68%	67.68%	3.91	0.221	29.19%	29.19%
collectorless scavenger - 3 minutes	36.76	3.55%	9.20%	2.97	0.105	16.80%	84.47%	3.31	0.117	15.53%	44.72%
collectorless scavenger II - 2.5 minutes	0.00	0.00%	9.20%	0.00	0.000	0.00%	84.47%	0.00	0.000	0.00%	44.72%
zinc rougher - time 1 minute	131.77	12.72%	21.92%	0.31	0.039	6.28%	90.76%	2.20	0.280	36.99%	81.71%
zinc rougher - time 2 minutes A	44.81	4.33%	26.25%	0.30	0.013	2.07%	92.83%	0.70	0.030	4.00%	85.71%
zinc rougher - time 2 minutes B	0.00	0.00%	26.25%	0.00	0.000	0.00%	92.83%	0.00	0.000	0.00%	85.71%
zinc scavenger - time 2 minutes A	60.70	5.87%	32.11%	0.16	0.009	1.50%	94.32%	0.38	0.022	2.95%	[illegible]
zinc scavenger - time 2 minutes B	14.57	1.40%	[illegible]	[illegible]	[illegible]	0.38%	94.70%	0.43	0.006	0.80%	89.46%
zinc scavenger - time 2 minutes C	0.00	0.00%	33.52%	0.00	0.000	0.00%	94.70%	0.00	0.000	0.00%	89.46%
final tails	688.60	66.48%	100.00%	0.05	0.033	5.30%	100.00%	0.12	0.080	10.54%	100.00%
reconstituted feed	1035.75				0.628	100.00%			0.757	100.00%	

sample reference	ZINC MASS BALANCE zinc assay (%)	zinc units	zinc recovery stage	zinc recovery total	IRON MASS BALANCE iron assay (%)	iron units	iron recovery stage	iron recovery total
collectorless rougher - 1 minute	12.48	0.705	6.88%	6.88%	27.57	1.557	5.21%	5.21%
collectorless scavenger - 3 minutes	14.40	0.511	4.99%	11.87%	28.88	1.025	3.43%	8.64%
collectorless scavenger II - 2.5 minutes	0.00	0.000	0.00%	11.87%	0.00	0.000	0.00%	8.64%
zinc rougher - time 1 minute	45.43	5.780	56.43%	68.31%	13.22	1.682	5.63%	14.27%
zinc rougher - time 2 minutes A	35.66	1.543	15.06%	83.37%	16.79	0.726	2.43%	16.71%
zinc rougher - time 2 minutes B	0.00	0.000	0.00%	83.37%	0.00	0.000	0.00%	16.71%
zinc scavenger - time 2 minutes A	25.80	1.514	14.79%	98.15%	26.13	1.534	5.13%	21.84%
zinc scavenger - time 2 minutes B	3.53	0.049	0.48%	98.64%	37.03	0.519	1.74%	23.58%
zinc scavenger - time 2 minutes C	0.00	0.000	[illegible]	[illegible]	[illegible]	[illegible]	0.00%	23.58%
final tails	0.21	0.140	1.36%	100.00%	34.34	22.830	76.42%	100.00%
reconstituted feed		10.242	100.00%			29.873	100.00%	

TEST SUMMARY:	sample weight	mass pull sample	mass pull total	copper assay %	copper recovery stage	copper recovery total	lead assay %	lead recovery stage	lead recovery total	zinc assay %	zinc recovery stage	zinc recovery total	iron assay %	iron recovery stage	iron recovery total
collectorless flotation	95.26	9.20%	9.20%	5.76	84.47%	84.47%	3.68	44.72%	44.72%	13.22	11.87%	11.87%	28.08	8.64%	8.64%
zinc rougher flotation	176.58	17.05%	26.25%	0.31	8.35%	92.83%	1.82	41.00%	85.71%	42.95	71.50%	83.37%	14.13	8.06%	16.71%
zinc scavenger flotation	75.31	7.27%	33.52%	0.16	1.88%	94.70%	0.39	3.74%	89.46%	21.51	15.27%	98.64%	28.23	6.87%	23.58%
final flotation tails	688.60	66.48%	100.00%	0.05	5.30%	100.00%	0.12	10.54%	100.00%	0.21	1.36%	100.00%	34.34	76.42%	100.00%

11-301 Collectorless flotation followed by zinc flotation.

F L O T A T I O N   C O N D I T I O N S

sample reference	pH	activator added g/t	Pre-conditioning gas	Pre-conditioning time	collector type	collector addition g/t	flotation gas
collectorless rougher - 1 minute	9.5	-	air	10 min	-	-	air
collectorless scavenger - 3 minutes	9.5	-	-	-	-	-	air
zinc rougher - 1 minute	10.5	1100	none	5 min	KEX	35	air
zinc rougher - 2 minutes	10.5	-	-	-	-	-	air
zinc scavenger - 2 minutes A	10.5	-	-	-	KEX	20	air
zinc scavenger - 2 minutes B	10.5	-	-	-	-	-	air

GRINDING CONDITIONS:

20 minutes, mild steel charge

1100 g/t zinc sulphate

NOTE:

Plant xanthate contains 50% ethyl xanthate and 50% dithiophosphate (Cyanamid 241)

11-301 Collectorless flotation followed by zinc flotation.

12. APPENDIX 4: KIDD CREEK TESTWORK

STANDARD AND NITROGEN FLOTATION

12-101 Bulk copper,lead flotation in air, pyrite flotation in air and zinc flotation in air.

12-102 Bulk copper,lead flotation in air, pyrite flotation in nitrogen and zinc flotation in air.

12-103 Bulk copper,lead flotation in air, pyrite flotation in gas containing 95% nitrogen and 5% oxygen, and zinc flotation in air.

12-104 Bulk copper,lead flotation in air, pyrite flotation in gas containing 90% nitrogen and 10% oxygen, and zinc flotation in air.

sample reference	SOLIDS MASS BALANCE sample weight	mass pull sample	mass pull total	COPPER MASS BALANCE copper assay (%)	copper units	copper recovery stage	copper recovery total	LEAD MASS BALANCE lead assay (%)	lead units	lead recovery stage	lead recovery total	ZINC MASS BALANCE zinc assay (%)	zinc units	zinc recovery stage	zinc recovery total	IRON MASS BALANCE iron assay (%)	iron units	iron recovery stage	iron recovery total
copper/lead rghr - 2 minute A	53.30	5.97%	5.97%	8.58	0.512	63.85%	63.85%	9.12	0.544	32.96%	32.96%	13.40	0.800	12.1.%	12.13%	24.60	1.468	7.18%	7.18%
copper/lead rghr - 2 minute B	30.30	3.39%	9.36%	3.27	0.111	13.83%	77.69%	8.62	0.293	17.71%	50.66%	16.60	0.563	8.54%	20.67%	23.50	0.797	3.90%	11.07%
copper/lead rghr - 2 minute C	26.30	2.95%	12.31%	1.52	0.045	5.58%	83.27%	7.30	0.215	13.02%	63.68%	18.40	0.542	8.22%	28.88%	24.90	0.733	3.58%	14.66%
copper/lead rghr - 2 minute D	31.00	3.47%	15.78%	0.94	0.033	4.07%	87.34%	3.28	0.114	6.89%	70.57%	14.70	0.510	7.74%	36.62%	27.30	0.948	4.63%	19.29%
pyrite rougher - 2 minutes A	15.90	1.78%	17.56%	0.86	0.015	1.91%	89.25%	2.44	0.043	2.63%	73.20%	15.50	0.276	4.18%	40.81%	24.80	0.442	2.15%	21.45%
pyrite rougher - 2 minutes B	11.80	1.32%	18.88%	0.53	0.007	0.87%	90.12%	2.37	0.031	1.90%	75.10%	11.80	0.156	2.36%	43.17%	27.60	0.365	1.78%	23.23%
pyrite rougher - 2 minutes C	10.60	1.19%	20.07%	0.40	0.005	0.59%	90.71%	1.94	0.023	1.39%	76.49%	11.80	0.140	2.12%	45.29%	29.60	0.351	1.72%	24.95%
pyrite rougher - 2 minutes D	10.50	1.18%	21.25%	0.29	0.003	0.43%	91.14%	1.47	0.017	1.05%	77.54%	9.59	0.113	1.71%	47.00%	32.00	0.376	1.84%	26.79%
zinc rougher - 30 seconds	22 80	2.55%	23.80%	0.15	0.004	0.48%	91.62%	0.40	0.010	0.62%	78.16%	47.60	1.215	18.43%	65.43%	9.31	0.238	1.16%	27.95%
zinc rougher - 1 minute	20.90	2.34%	26.14%	0.18	0.004	0.53%	92.14%	0.57	0.013	0.81%	78.97%	40.20	0.941	14.27%	79.70%	11.20	0.262	1.28%	29.23%
zinc rougher B - 30 seconds	31.60	3.54%	29.68%	0.14	0.005	0.62%	92.76%	0.82	0.029	1.76%	80.72%	23.00	0.814	12.34%	92.04%	26.80	0.948	4.64%	33.87%
zinc rougher B - 1 minute	54.30	6.08%	35.76%	0.11	0.007	0.83%	93.59%	0.80	0.049	2.95%	83.67%	3.04	0.185	2.80%	94.84%	33.40	2.031	9.93%	43.80%
final tails	573 60	64.24%	100.00%	0.08	0.051	6.41%	100.00%	0.42	0.270	16.33%	100.00%	0.53	0.340	5.16%	100.00%	17.90	11.499	56.20%	100.00%
reconstituted feed	892.90				0.802	100.00%			1.652	100.00%			6.596	100.00%			20.460	100.00%	

TEST SUMMARY:	sample weight	mass pull sample	mass pull total	copper assay %	recovery stage	recovery total	lead assay %	recovery stage	recovery total	zinc assay %	recovery stage	recovery total	iron assay %	recovery stage	recovery total
copper/lead flotation	140.90	15.78%	15.78%	4.44	87.34%	87.34%	7.39	70.57%	70.57%	15.31	36.62%	36.62%	25.01	19.29%	19.29%
pyrite flotation	48.80	5.47%	21.25%	0.56	3.80%	91.14%	2.11	6.97%	77.54%	12.53	10.38%	47.00%	28.07	7.50%	26.79%
zinc rougher flotation	43.70	4.89%	26.14%	0.16	1.00%	92.14%	0.48	1.43%	78.97%	44.06	32.69%	79.70%	10.21	2.44%	29.23%
zinc rougher flotation B	85.90	9.62%	35.76%	0.12	1.45%	93.59%	0.81	4.70%	83.67%	10.38	15.14%	94 84%	30.97	14.56%	43.80%
final flotation tails	573.60	64.24%	100.00%	0.08	6.41%	100.00%	0.42	16.33%	100.00%	0.53	5.16%	100.00%	17.90	56.20%	100.00%

12-101 Bulk copper,lead flotation in air, pyrite flotation in air and zinc flotation in air.

FLOTATION CONDITIONS

sample reference	pH	activator added g/t	Pre-conditioning gas	Pre-conditioning time	collector type	collector addition g/t	flotation gas
copper lead rougher - 2 minute A	10.2	-	air	10 min	SIPX	5	air
copper lead rougher - 2 minute B	10.2	-	-	-	SIPX	5	air
copper lead rougher - 2 minute C	10.2	-	-	-	SIPX	5	air
copper lead rougher - 2 minute D	10.2	-	-	-	SIPX	5	air
pyrite rougher - time 2 minutes A	9.5	-	air	5 min	SIPX	5	air
pyrite rougher - time 2 minutes B	9.5	-	air	2 min	SIPX	5	air
pyrite rougher - time 2 minutes C	9.5	-	air	2 min	SIPX	5	air
pyrite rougher - time 2 minutes D	9.5	-	air	2 min	SIPX	5	air
zinc rougher - time 30 seconds	11.0	1200	-	5 min	-	-	air
zinc rougher - time 1 minute	11.0	-	-	-	-	-	air
zinc rougher B - time 30 seconds	11.0	-	-	-	SIPX	50	air
zinc rougher B - time 1 minute	11.0	-	-	-	-	-	air

DISSOLVED OXYGEN LEVELS: ppm.	BEGINNING	END
copper/lead rougher - 2 minute A	7.5	10.8
copper/lead rougher - 2 minute B	7.3	10.7
copper/lead rougher - 2 minute C	6.5	8.2
copper/lead rougher - 2 minute D	6.3	7.8
pyrite rougher - time 2 minutes A	7.8	7.8
pyrite rougher - time 2 minutes B	7.8	7.8
pyrite rougher - time 2 minutes C	7.8	7.8
pyrite rougher - time 2 minutes D	7.8	7.8
zinc rougher - time 30 seconds	7.0	7.5
zinc rougher - time 1 minute	7.1	7.5
zinc rougher B - time 30 seconds	7.1	7.5
zinc rougher B - time 1 minute	7.1	7.5

GRINDING CONDITIONS:

30 minutes, mild steel charge

Zinc Sulphate, 1200 g/t

12-101 Bulk copper,lead flotation in air, pyrite flotation in air and zinc flotation in air.

sample reference	SOLIDS MASS BALANCE sample weight (grams)	mass pull sample	mass pull total	COPPER MASS BALANCE copper assay (%)	copper units	copper recovery stage	copper recovery total	LEAD MASS BALANCE lead assay (%)	lead units	lead recovery stage	lead recovery total	ZINC MASS BALANCE zinc assay (%)	zinc units	zinc recovery stage	zinc recovery total	IRON MASS BALANCE iron assay (%)	iron units	iron recovery stage	iron recovery total
copper/lead rghr - 2 minute A	35.30	3.76%	3.76%	9.36	0.352	51.55%	51.55%	6.00	0.225	13.93%	13.93%	10.00	0.376	5.85%	5.85%	25.00	0.939	5.13%	5.13%
copper/lead rghr - 2 minute B	20.80	2.21%	5.97%	6.52	0.144	21.16%	72.71%	10.20	0.226	13.95%	27.88%	14.20	0.314	4.89%	10.74%	23.30	0.516	2.81%	7.94%
copper/lead rghr - 2 minute C	13.20	1.40%	7.37%	3.12	0.044	6.43%	79.14%	11.10	0.156	9.64%	37.52%	17.70	0.249	3.87%	14.61%	22.40	0.315	1.72%	9.66%
copper/lead rghr - 2 minute D	12.80	1.36%	8.74%	1.91	0.026	3.81%	82.95%	10.10	0.138	8.50%	46.02%	19.00	0.259	4.03%	18.64%	24.00	0.327	1.78%	11.44%
pyrite rougher - 2 minutes A	26.50	2.87%	11.56%	0.80	0.073	3.31%	86.26%	11.30	0.319	19.69%	65.72%	11.10	0.313	4.87%	23.51%	28.40	0.891	4.37%	15.81%
pyrite rougher - 2 minutes B	34.00	3.62%	15.17%	0.24	0.009	1.27%	87.54%	2.25	0.081	5.03%	70.75%	4.82	0.174	2.71%	26.22%	32.00	1.158	6.32%	22.13%
pyrite rougher - 2 minutes C	51.90	5.52%	20.70%	0.12	0.007	0.97%	88.51%	1.05	0.058	3.58%	74.33%	3.23	0.178	2.78%	29.00%	33.00	1.822	9.95%	32.08%
pyrite rougher - 2 minutes D	82.00	8.73%	29.42%	0.12	0.010	1.54%	90.04%	0.81	0.071	4.37%	78.70%	3.59	0.313	4.88%	33.87%	32.20	2.810	15.33%	47.41%
zinc rougher 30 seconds	43.90	4.67%	34.09%	0.18	0.008	1.23%	91.28%	0.50	0.023	1.44%	80.15%	49.70	2.322	36.13%	70.01%	8.74	0.408	2.23%	49.64%
zinc rougher 1 minute	17.20	1.83%	35.92%	0.19	0.003	0.51%	91.79%	0.54	0.010	0.61%	80.76%	44.70	0.818	12.73%	82.74%	10.20	0.187	1.02%	50.66%
zinc rougher B 30 seconds	15.50	1.65%	37.57%	0.25	0.004	0.60%	92.39%	0.74	0.012	0.75%	81.51%	29.50	0.487	7.57%	90.31%	15.10	0.249	1.36%	52.02%
zinc rougher B 1 minute	13.10	1.39%	38.97%	0.22	0.003	0.45%	92.84%	0.88	0.012	0.76%	82.27%	0.74	0.122	1.90%	92.21%	35.20	0.491	2.68%	54.70%
final tails	573.60	61.03%	100.00%	0.08	0.049	7.16%	100.00%	0.47	0.287	17.73%	100.00%	0.82	0.500	7.79%	100.00%	13.60	8.301	45.30%	100.00%
reconstituted feed	939.80				0.682	100.00%			1.618	100.00%			6.425	100.00%			18.322	100.00%	

TEST SUMMARY:

	sample weight	mass pull sample	mass pull total	copper assay %	recovery stage	recovery total	lead assay %	recovery stage	recovery total	zinc assay %	recovery stage	recovery total	iron assay %	recovery stage	recovery total
copper lead flotation	82.10	8.74%	8.74%	6.48	82.95%	82.95%	8.52	46.02%	46.02%	13.71	18.64%	18.64%	24.00	11.44%	11.44%
pyrite flotation	194.40	20.69%	29.42%	0.23	7.09%	90.04%	2.56	32.68%	78.70%	4.73	15.24%	33.87%	31.86	35.97%	47.41%
zinc rougher flotation	61.10	6.50%	35.92%	0.18	1.74%	91.79%	0.51	2.05%	80.76%	40.29	48.87%	82.74%	9.15	3.25%	50.66%
zinc rougher flotation	28.60	3.04%	38.97%	0.24	1.05%	92.84%	0.88	1.51%	82.27%	19.99	9.47%	92.21%	24.31	4.04%	54.70%
final flotation tails	573.60	61.03%	100.00%	0.08	7.16%	100.00%	0.47	17.73%	100.00%	0.82	7.79%	100.00%	13.60	45.30%	100.00%

12-102 Bulk copper,lead flotation in air, pyrite flotation in nitrogen and zinc flotation in air.

test number

F L O T A T I O N   C O N D I T I O N S

sample reference	pH	activator added g/t	pre-conditioning gas	pre-conditioning time	collector type	collector addition g/t	flotation gas
copper/lead rougher - 2 minute A	10.2	-	air	10 min	SIPX	5	air
copper/lead rougher - 2 minute B	10.2	-	-	-	SIPX	5	air
copper/lead rougher - 2 minute C	10.2	-	-	-	SIPX	5	air
copper/lead rougher - 2 minute D	10.2	-	-	-	SIPX	5	air
pyrite rougher - time 2 minutes A	9.5	-	nitrogen	5 min	SIPX	5	nitrogen
pyrite rougher - time 2 minutes B	9.5	-	nitrogen	2 min	SIPX	5	nitrogen
pyrite rougher - time 2 minutes C	9.5	-	nitrogen	2 min	SIPX	5	nitrogen
pyrite rougher - time 2 minutes D	9.5	-	nitrogen	2 min	SIPX	5	nitrogen
zinc rougher - time 30 seconds	11.0	1200	-	5 min	-	-	air
zinc rougher - time 1 minute	11.0	-	-	-	-	-	air
zinc rougher B - time 30 seconds	11.0	-	-	-	SIPX	25	air
zinc rougher B - time 1 minute	11.0	-	-	-	-	-	air

DISSOLVED OXYGEN LEVELS: ppm.	BEGINNING	END
copper/lead rougher - 2 minute A	7.0	9.3
copper/lead rougher - 2 minute B	5.8	9.8
copper/lead rougher - 2 minute C	5.5	10.3
copper/lead rougher - 2 minute D	5.4	9.3
pyrite rougher - time 2 minutes A	0.5	0.5
pyrite rougher - time 2 minutes B	0.5	0.5
pyrite rougher - time 2 minutes C	0.5	0.5
pyrite rougher - time 2 minutes D	0.5	0.5
zinc rougher - time 30 seconds	7.1	7.9
zinc rougher - time 1 minute	7.3	7.9
zinc rougher B - time 30 seconds	7.6	7.8
zinc rougher B - time 1 minute	7.4	7.9

GRINDING CONDITIONS:

30 minutes, mild steel charge

Zinc Sulphate, 1200 g/t

12-102 Bulk copper,lead flotation in air, pyrite flotation in nitrogen and zinc flotation in air.

sample reference	SOLIDS MASS BALANCE sample weight (grams)	mass pull sample	mass pull total	COPPER MASS BALANCE copper assay (%)	copper units	copper recovery stage	copper recovery total	LEAD MASS BALANCE lead assay (%)	lead units	lead recovery stage	lead recovery total	ZINC MASS BALANCE zinc assay (%)	zinc units	zinc recovery stage	zinc recovery total	IRON MASS BALANCE iron assay (%)	iron units	iron recovery stage	iron recovery total
copper/lead rghr - 2 minute A	26.50	2.78%	2.78%	8.04	0.224	27.09%	27.09%	11.00	0.306	10.31%	10.31%	15.50	0.431	6.29%	6.29%	24.60	0.680	3.29%	3.29%
copper/lead rghr - 2 minute B	29.60	3.11%	5.89%	11.09	0.342	42.62%	70.52%	8.02	0.249	14.91%	33.22%	11.20	0.348	5.08%	11.38%	25.60	0.795	3.83%	7.12%
copper/lead rghr - 2 minute C	19.70	2.07%	7.95%	1.24	0.026	3.20%	73.72%	8.39	0.173	10.38%	43.61%	18.40	0.380	5.55%	16.93%	25.40	0.525	2.53%	9.65%
copper/lead rghr - 2 minute D	11.40	1.20%	9.15%	0.94	0.011	1.40%	75.12%	5.67	0.068	4.06%	47.67%	17.70	0.212	3.09%	20.02%	28.20	0.337	1.62%	11.28%
pyrite rougher - 2 minutes A	16.50	1.73%	10.88%	3.31	0.057	7.15%	82.27%	9.22	0.160	9.56%	57.22%	18.40	0.319	4.65%	24.68%	22.80	0.395	1.90%	13.18%
pyrite rougher - 2 minutes B	21.50	2.26%	13.14%	1.77	0.040	4.98%	87.25%	8.26	0.186	11.16%	68.38%	19.80	0.447	6.52%	31.20%	23.50	0.530	2.55%	15.73%
pyrite rougher - 2 minutes C	44.70	4.69%	17.83%	0.10	0.005	0.59%	87.83%	0.90	0.042	2.57%	70.91%	6.05	0.284	4.14%	35.34%	36.20	1.698	8.18%	23.91%
pyrite rougher - 2 minutes D	48.50	5.09%	22.92%	0.25	0.013	1.59%	89.42%	2.28	0.116	6.95%	77.85%	8.34	0.424	6.20%	41.54%	38.80	1.975	9.51%	33.42%
pyrite rougher - 2 minutes E	82.50	8.66%	31.58%	0.11	0.010	1.19%	90.61%	0.64	0.055	3.32%	81.17%	5.08	0.440	6.42%	47.96%	42.60	3.688	17.76%	51.18%
zinc rougher - 30 seconds	38.50	4.04%	35.62%	0.14	0.006	0.71%	91.32%	0.40	0.016	0.97%	82.14%	50.70	2.048	29.91%	77.88%	8.42	0.349	1.64%	52.82%
zinc rougher - 1 minute	21.10	2.21%	37.83%	0.17	0.004	0.47%	91.79%	0.52	0.012	0.69%	82.83%	41.20	0.912	13.32%	91.20%	12.60	0.279	1.34%	54.16%
zinc rougher B - 30 seconds	11.60	1.22%	39.05%	0.23	0.003	0.35%	92.13%	0.86	0.010	0.63%	83.45%	19.10	0.233	3.40%	94.60%	24.10	0.293	1.41%	55.57%
zinc rougher B - 1 minute	18.20	1.91%	40.96%	0.21	0.004	0.50%	92.63%	0.87	0.017	0.99%	84.45%	4.23	0.081	1.18%	95.78%	41.00	0.783	3.77%	59.34%
final tails	562.60	59.04%	100.00%	0.10	0.059	7.37%	100.00%	0.44	0.260	15.55%	100.00%	0.49	0.289	4.22%	100.00%	14.30	8.443	40.66%	100.00%
reconstituted feed	952.90				0.802	100.00%			1.671	100.00%			6.848	100.00%			20.766	100.00%	

TEST SUMMARY:	sample weight	mass pull sample	mass pull total	copper assay %	copper recovery stage	copper recovery total	lead assay %	lead recovery stage	lead recovery total	zinc assay %	zinc recovery stage	zinc recovery total	iron assay %	iron recovery stage	iron recovery total
copper/lead flotation	87.20	9.15%	9.15%	6.50	75.12%	75.12%	8.70	47.67%	47.67%	14.90	20.02%	20.02%	25.59	11.28%	11.28%
pyrite flotation	213.70	22.43%	31.58%	0.51	15.49%	90.61%	2.25	33.50%	81.17%	6.57	27.94%	47.96%	20.50	39.90%	51.18%
zinc rougher flotation	59.60	6.25%	37.83%	0.15	1.18%	91.79%	0.44	1.66%	82.83%	47.34	43.24%	91.20%	9.90	2.98%	54.16%
zinc rougher flotation B	29.80	3.13%	40.96%	0.22	0.85%	92.63%	0.87	1.62%	84.45%	10.02	4.58%	95.78%	34.42	5.18%	59.34%
final flotation tails	562.60	59.04%	100.00%	0.10	7.37%	100.00%	0.44	15.55%	100.00%	0.49	4.22%	100.00%	14.30	40.66%	100.00%

12-103 Bulk copper, lead flotation in air, pyrite flotation in gas containing 95% nitrogen, 5% oxygen, and zinc flotation in air.

test number

F L O T A T I O N   C O N D I T I O N S

sample reference	pH	activator added g/t	Pre-conditioning gas	Pre-conditioning time	collector type	collector addition g/t	flotation gas
copper/lead rougher - 2 minute A	10.2	-	air	10 min	SIPX	5	air
copper/lead rougher - 2 minute B	10.2	-	-	-	SIPX	5	air
copper/lead rougher - 2 minute C	10.2	-	-	-	SIPX	5	air
copper/lead rougher - 2 minute D	10.2	-	-	-	SIPX	5	air
pyrite rougher - time 2 minutes A	9.5	-	95% N2	5 min	SIPX	5	95% N2
pyrite rougher - time 2 minutes B	9.5	-	95% N2	2 min	SIPX	5	95% N2
pyrite rougher - time 2 minutes C	9.5	-	95% N2	2 min	SIPX	5	95% N2
pyrite rougher - time 2 minutes D	9.5	-	95% N2	2 min	SIPX	5	95% N2
zinc rougher - time 30 seconds	11.0	1200	-	5 min	SIPX	25	air
zinc rougher - time 1 minute	11.0	-	-	-	-	-	air
zinc rougher B - time 30 seconds	11.0	-	-	-	SIPX	25	air
zinc rougher B - time 1 minute	11.0	-	-	-	-	-	air

DISSOLVED OXYGEN LEVELS: ppm.	BEGINNING	END
copper/lead rougher - 2 minute A	6.6	10.0
copper/lead rougher - 2 minute B	6.8	10.1
copper/lead rougher - 2 minute C	6.3	10.6
copper/lead rougher - 2 minute D	7.2	10.7
pyrite rougher - time 2 minutes A	3.5	2.9
pyrite rougher - time 2 minutes B	2.6	2.5
pyrite rougher - time 2 minutes C	2.5	2.5
pyrite rougher - time 2 minutes D	2.5	2.5
zinc rougher - time 30 seconds	8.3	9.6
zinc rougher - time 1 minute	8.5	9.5
zinc rougher B - time 30 seconds	8.2	9.1
zinc rougher B - time 1 minute	8.3	9.5

GRINDING CONDITIONS:

30 minutes, mild steel charge

Zinc Sulphate, 1200 g/t

12-103 Bulk copper,lead flotation in air, pyrite flotation in gas containing 95% nitrogen, 5% oxygen, and zinc flotation in air.

sample reference	SOLIDS MASS BALANCE: sample weight (grams)	mass pull sample	mass pull total	COPPER MASS BALANCE: copper assay (%)	units	copper recovery stage	copper recovery total	LEAD MASS BALANCE: lead assay (%)	units	lead recovery stage	lead recovery total	ZINC MASS BALANCE: zinc assay (%)	units	zinc recovery stage	zinc recovery total	IRON MASS BALANCE: iron assay (%)	units	iron recovery stage	iron recovery total
copper/lead rghr - 2 minute A	32.80	3.50%	3.50%	9.69	0.339	45.92%	45.92%	6.77	0.237	14.48%	14.48%	10.20	0.357	5.34%	5.34%	26.10	0.913	4.40%	4.40%
copper/lead rghr - 2 minute B	28.26	3.01%	6.51%	6.43	0.194	26.25%	72.17%	9.02	0.272	16.62%	31.10%	15.80	0.476	7.12%	12.46%	22.90	0.690	3.33%	7.73%
copper/lead rghr - 2 minute C	22.87	2.44%	8.95%	2.51	0.061	8.29%	80.46%	11.90	0.290	17.75%	48.85%	20.40	0.498	7.44%	19.90%	22.80	0.556	2.68%	10.41%
copper/lead rghr - 2 minute D	18.11	1.93%	10.89%	1.33	0.026	3.48%	83.94%	5.62	0.109	6.64%	55.49%	18.40	0.355	5.32%	25.22%	23.80	0.460	2.22%	12.63%
pyrite rougher - 2 minutes A	14.51	1.55%	12.43%	1.06	0.016	2.22%	86.17%	6.67	0.103	6.31%	61.80%	19.10	0.296	4.42%	29.64%	24.00	0.371	1.79%	14.42%
pyrite rougher - 2 minutes B	15.80	1.69%	14.13%	0.65	0.011	1.49%	87.66%	5.84	0.099	6.05%	67.84%	17.30	0.293	4.38%	34.02%	24.60	0.417	2.01%	16.43%
pyrite rougher - 2 minutes C	12.89	1.38%	15.50%	0.47	0.006	0.88%	88.53%	3.84	0.053	3.23%	71.07%	15.70	0.216	3.23%	37.25%	27.90	0.382	1.84%	18.27%
pyrite rougher - 2 minutes D	8.50	0.91%	16.41%	0.39	0.004	0.48%	89.01%	2.46	0.022	1.36%	72.44%	14.60	0.132	1.98%	39.23%	26.50	0.240	1.16%	19.43%
zinc rougher - 30 seconds	45.13	4.81%	21.22%	0.13	0.006	0.85%	89.86%	0.65	0.031	1.91%	74.35%	48.10	2.316	34.63%	73.85%	10.10	0.486	2.34%	21.77%
zinc rougher - 1 minute	20.80	2.22%	23.44%	0.15	0.003	0.45%	90.31%	0.90	0.020	1.22%	75.57%	37.80	0.839	12.54%	86.40%	15.00	0.333	1.60%	23.38%
zinc rougher B - 30 seconds	15.28	1.63%	25.07%	0.18	0.003	0.40%	90.71%	1.08	0.018	1.08%	76.64%	22.90	0.373	5.58%	91.98%	22.00	0.359	1.73%	25.11%
zinc rougher B - 1 minute	36.80	3.93%	29.00%	0.12	0.005	0.64%	91.35%	0.87	0.034	2.09%	78.73%	4.26	0.167	✓2.50%	94.48%	37.60	1.476	7.12%	32.22%
final tails	665.60	71.00%	100.00%	0.09	0.064	8.65%	100.00%	0.49	0.348	21.27%	100.00%	0.52	0.369	5.52%	100.00%	19.80	14.059	67.78%	100.00%
reconstituted feed	937.43				0.738	100.00%			1.636	100.00%			6.687	100.00%			20.743	100.00%	

TEST SUMMARY:	sample weight	mass pull sample	mass pull total	copper assay %	copper recovery stage	copper recovery total	lead assay %	lead recovery stage	lead recovery total	zinc assay %	zinc recovery stage	zinc recovery total	iron assay %	iron recovery stage	iron recovery total
copper/lead flotation	102.04	10.89%	10.89%	5.69	83.94%	83.94%	8.34	55.49%	55.49%	15.49	25.22%	25.22%	24.07	12.63%	12.63%
pyrite flotation	51.78	5.52%	16.41%	0.68	5.07%	89.01%	5.02	16.95%	72.44%	16.96	14.01%	39.23%	25.54	6.80%	19.43%
zinc rougher flotation	65.93	7.03%	23.44%	0.14	1.30%	90.31%	0.73	3.13%	75.57%	44.85	47.17%	86.40%	11.65	3.95%	23.38%
zinc rougher flotation	52.08	5.56%	29.00%	0.14	1.04%	91.35%	0.93	3.16%	78.73%	9.73	8.08%	94.48%	33.02	8.84%	32.22%
final flotation tails	665.60	71.00%	100.00%	0.09	8.65%	100.00%	0.49	21.27%	100.00%	0.52	5.52%	100.00%	19.80	67.78%	100.00%

12-104 Bulk copper,lead flotation in air, pyrite flotation in gas containing 90% nitrogen and 10% oxygen, and zinc flotation in air.

FLOTATION CONDITIONS

sample reference	pH	modifier added g/t	Pre-conditioning gas	Pre-conditioning time	collector type	collector addition g/t	flotation gas
copper/lead rougher - 2 minute A	10.2	-	air	10 min	SIPX	5	air
copper/lead rougher - 2 minute B	10.2	-	-	-	SIPX	5	air
copper/lead rougher - 2 minute C	10.2	-	-	-	SIPX	5	air
copper/lead rougher - 2 minute D	10.2	-	-	-	SIPX	5	air
pyrite rougher - time 2 minutes A	9.5	-	90% N2	5 min	SIPX	5	90% N2
pyrite rougher - time 2 minutes B	9.5	-	90% N2	2 min	SIPX	5	90% N2
pyrite rougher - time 2 minutes C	9.5	-	90% N2	2 min	SIPX	5	90% N2
pyrite rougher - time 2 minutes D	9.5	-	90% N2	2 min	SIPX	5	90% N2
zinc rougher - time 30 seconds	11.0	1200	-	5 min	SIPX	25	air
zinc rougher - time 1 minute	11.0	-	-	-	-	-	air
zinc rougher B - time 30 seconds	11.0	-	-	-	SIPX	25	air
zinc rougher B - time 1 minute	11.0	-	-	-	-	-	air

DISSOLVED OXYGEN LEVELS: ppm.

	BEGINNING	END
copper/lead rougher - 2 minute A	5.3	9.9
copper/lead rougher - 2 minute B	6.4	10.0
copper/lead rougher - 2 minute C	6.0	10.0
copper/lead rougher - 2 minute D	6.0	10.3
pyrite rougher - time 2 minutes A	5.7	5.7
pyrite rougher - time 2 minutes B	5.7	5.7
pyrite rougher - time 2 minutes C	5.7	5.7
pyrite rougher - time 2 minutes D	5.7	5.7
zinc rougher - time 30 seconds	8.5	9.3
zinc rougher - time 1 minute	9.4	9.7
zinc rougher B - time 30 seconds	9.1	9.9
zinc rougher B - time 1 minute	8.2	10.1

GRINDING CONDITIONS:

30 minutes. mild steel charge

Zinc Sulphate. 1200 g/t

12-104 Bulk copper,lead flotation in air, pyrite flotation in gas containing 90% nitrogen and 10% oxygen, and zinc flotation in air.

13. APPENDIX 5

DISSOLVED OXYGEN CONSUMPTION IN A FLOTATION COLUMN

It is possible to make a rough estimate of the oxygen consumption in a flotation column based on the results reported in this thesis.

Basis:

10 metre column with 5 cm inside diameter. Total volume capacity of 0.02 m^3. Bubbles rise typically at a rate of 2 cm per second, so the retention time for the gas is 500 seconds. The pulp retention time is assumed at 20 minutes, giving a feed rate of 0.8 litres per minute. At a pulp density of 1.25 kg per litre, the mass feed rate is 1 kilogram per minute.

Oxygen balance

Oxygen available:

The retention time of the air is 500 seconds, and the gas hold-up, 20% of 0.02 m3 (0.004 m3). From this, the gas feed rate can be calculated at 0.48 litres per minute which, at a density of 1.293grams per litre (at S.T.P.) is 0.6grams per minute. This contains 19% oxygen, and represents an oxygen feed rate of 0.12grams per minute.

Oxygen consumption (from mineral oxygen demand alone):

Figure 4.22 plots the drop in oxygen content in nitrogenated water, and Kidd Creek pulp. The oxygen level in the pulp drops faster than in the water, because of the oxygen demand from the mineral. Difference between the slopes of the two plots (in the first twenty seconds, i.e. before the oxygen levels are depleted and the two lines converge again) represents the rate of consumption of oxygen through mineral oxidation:

Drop of oxygen level in water 1.8 ppm in 20 seconds.

Drop of oxygen level in pulp 7.0 ppm in 20 seconds.

oxygen demand during the 20 second period 5.2 ppm.

This matches the oxygen demand measurements previously made on Canadian Shield ores (94). Their work showed that as the pulp ages its oxygen demand drops. A profile from their work which matches Kidd Creek ore is given in Figure 13.1.

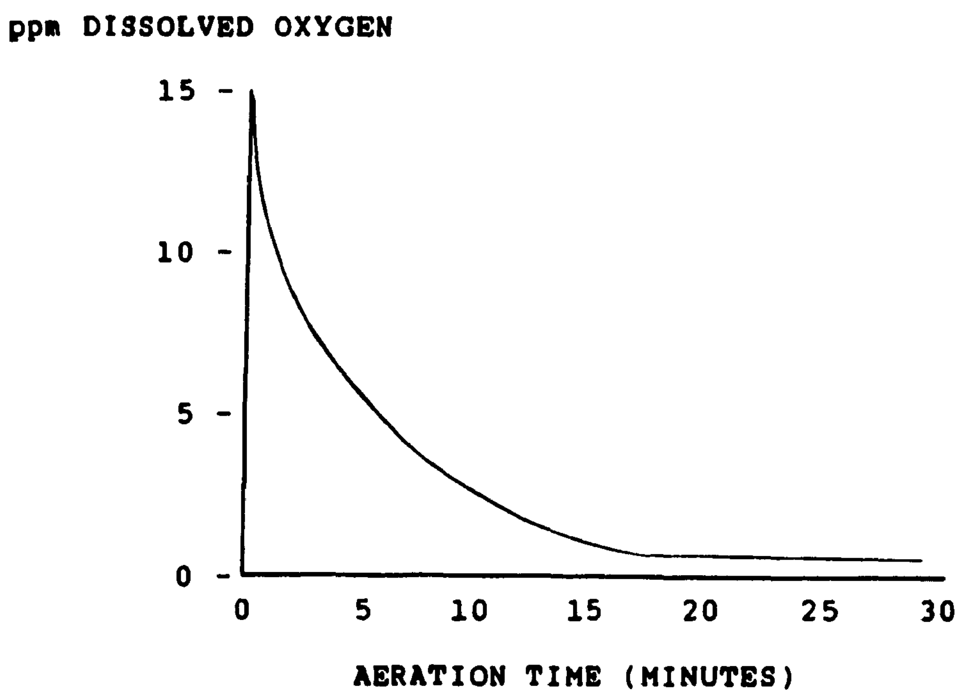

FIGURE 13.1 - Approximate oxygen demand profile for Kidd Creek ore.

From Figure 13.1, the total oxygen demand for the pulp during a 20 minute residence time can be estimated by linear approximation of the integration to 20 minutes as 90 ppm.

The feed rate to the column is 1kg per minute, and this has an oxygen consumption rate of 90 ppm. So the oxygen demand from the pulp will be 0.09 grams per minute.

SUMMARY:

Oxygen supply from air : 0.12grams per minute

Oxygen requirement for oxidising the pulp : 0.09grams per minute

Oxygen remaining in the air at the top: 0.03grams per minute, which is a quarter of the oxygen content of the air entering the column. The gas would therefore be 95% nitrogen and 5% oxygen.

Pyrite is activated at such levels of oxygen content.