ABSTRACT

In the past several years, considerable effort has been directed by Lakefield Research towards improving the efficiency of mineral separations by flotation.

Significant improvements were achieved during the processing of oxide minerals, and this was made possible by the development of new reagent mixtures which allowed much more efficient and selective separations of the valuable minerals. Examples of such improvements are the flotation of sedimentary phosphates and the flotation of rare earth minerals.

During the flotation of sulphides minerals, major improvements resulted from the use of new depressant families which significantly increased the separation efficiency between various sulphide minerals.

Circuit configuration is also shown to have a major influence on metallurgical results.

For the metallurgist, the treatment of finely disseminated massive sulphide ores has long been a most difficult task; recently, however, high intensity conditioning has proved, at the laboratory and the pilot scale, that it could well be the solution to that problem.

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INTRODUCTION

During the course of the numerous projects carried out under contract for the mining industry, Lakefield Research has been several times faced with metallurgical problems for which conventional procedures had no satisfactory solution. New concepts had therefore to be developed in order to provide technical and economical answers to those problems.

This paper summarizes some of the progress made by Lakefield metallurgical staff in particular areas such as the development of new collectors for the flotation of oxidic materials (phosphates, rare earth oxides), and that of new depressants for improved separation of various sulphide minerals. Examples are also given to illustrate the influence of circuit configuration on metallurgical results. Finally, high intensity conditioning has been recently applied to the treatment of finely disseminated sulphide ores, and successful applications of the procedure for copper ores are presented.

DEVELOPMENT OF NEW COLLECTOR MIXTURES FOR THE FLOTATION OF OXIDIC MINERALS

Although not as widely used as for the treatment of metallic sulfides, flotation represents an important process for the recovery of oxidic minerals such as carbonates, silicates, phosphates, and oxides. One major problem encountered during the processing of these minerals is the lack of selectivity, due to the non-specificity of collector adsorption and the froth structure.
New reagent mixtures have been developed by Lakefield Research in order to improve separation selectivity to recover such minerals as phenacite, bastnaesite, eudialyte and various copper oxide and phosphate minerals.

Examples of application of such reagent mixtures are given in the following paragraphs.

Flotation of Bastnaesite

Bastnaesite, $\text{(Ce, La, Pr ...)}\text{CO}_3\text{F}$, is contained in large deposits in California and China. In Mountain Pass, bastnaesite is separated from the gangue minerals (quartz, barite, calcite, strontianite) using a very complex flotation procedure, summarized in Figure No. 1.\(^{(1)}\)

Lakefield Research has recently developed some new collector blends to recover bastnaesite from complex ores.\(^{(3)}\) These blends are very ore specific. Accordingly both the blend and flowsheet must be tailored to the ore. A flowsheet developed for one particular application is shown. After a two-stage reverse gangue flotation and using the new collector blend, high grade concentrate was obtained with very high recoveries.

Flotation of Sedimentary Phosphates

Flotation is widely used to recover phosphate minerals from sedimentary siliceous ores. The flowsheet in general use can be simplified as shown in Figure No. 3.\(^{(4)}\)

The process is not very efficient, and recovery is usually low.

Using a newly developed collector blend (fatty acid-based) and a very simple flowsheet (Figure No. 4), high selectivity was obtained during
the flotation of phosphate from a sedimentary ore containing 7.2% P₂O₅. The results are illustrated in Figure No. 5.

NEW DEPRESSANT FAMILIES FOR SEPARATION OF POLYMETALLIC SULFIDES

Flotation chemistry is a major factor governing mineral separations by flotation. A large body of work has been devoted to improve the separation between metallic sulfides by finding more selective collectors, but little attention has been given to the role of modifiers and depressants, although these reagents play a decisive role in achieving selectivity and recovery in most of the complex massive sulphide ores.

Several of the new developments at Lakefield Research have focused on depressants and pulp modifiers specifically designed to improve inter-mineral selectivity and rate of flotation. Two different groups of depressants have been developed: organic complexes derived from lignin sulfonates, quebracho, starches, guar, dextrins modified by simple organic and inorganic compounds, and compounds derived from carbonic acid derivatives and inorganic salts. Both groups of depressants have found application in a number of refractory polymetallic ores where conventional reagents failed to achieve satisfactory selectivity. Organics such as high molecular weight lignin sulfonates, guar, starches and dextrins are known as depressants for massive sulphides on their own. Their application, however, is limited mainly because they are not sufficiently selective. Lakefield Research has developed three entire series of these selective organic and organic-inorganic mixtures known as "PK" "DS" and "LS" depressants.

The "DS" and "LS" reagents are not general purpose depressants such as conventional inorganic depressants but have to be adapted to specific ores; for example there are presently more than twenty formulations in the "DS"
series and more than ten in the "LS" series. The "PK" series is more general purpose and is presently marketed under the "Unamin" name by Hart Chemical in Guelph, Ontario, Canada. However, even these depressants require careful tailoring of the conditioning, dosage, and flowsheet for each ore.

These reagents are not general purpose depressants such as conventional inorganic depressants but have to be adapted to specific ores.

The wide range of "DS" depressants available allow for treatment of ores with process requirements of the following types:

a) For depression of pyrite during the treatment of refractory Cu-Zn and Cu-Pb-Zn ores.

b) As a replacement for cyanide during the treatment of Cu-Zn and Cu-Pb-Zn ores: with the use of these depressants, the cyanide can be reduced or completely eliminated from the circuit.

c) For depression of zinc during the treatment Cu-Zn, Pb-Zn or Cu-Pb-Zn ores.

The behaviour of "DS" depressants varies with the ore and therefore adjustment in the composition of a particular depressant is sometimes necessary to suit the application.

Examples of application of depressants from the "DS" family are given in the following paragraphs. Figure No.6 illustrates the effect of various depressants on the flotation of copper from a massive Cu-Zn ore while
Figure No. 7 shows the effect of a "DS" depressant on pyrite rejection during lead flotation from a lead-zinc ore. Significantly better selectivity is achieved when using the "DS" depressants.

Reagents of the "DS" family were tested in a commercial plant operation treating a lead-zinc ore at a rate of 96 tonnes per hour.

The results obtained in the commercial plant with and without the "DS" depressant are shown in Table No. 1.

TABLE NO. 1: Effects of the "DS" addition on the Commercial Plant Operation

<table>
<thead>
<tr>
<th>Depression Additions</th>
<th>Product</th>
<th>Wt %</th>
<th>Assays %</th>
<th>% Distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Pb</td>
<td>Zn</td>
<td>Pb</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>Pb Concentrate</td>
<td>5.03</td>
<td>38.84</td>
<td>1.60</td>
</tr>
<tr>
<td></td>
<td>Zn Concentrate</td>
<td>23.56</td>
<td>0.41</td>
<td>55.25</td>
</tr>
<tr>
<td></td>
<td>Zn Final Tailing</td>
<td>71.41</td>
<td>0.35</td>
<td>1.05</td>
</tr>
<tr>
<td></td>
<td>Head (Calc.)</td>
<td>100.00</td>
<td>2.30</td>
<td>13.85</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th></th>
<th>Pb</th>
<th>Zn</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>300 g/t</td>
<td>Pb Concentrate</td>
<td>3.06</td>
<td>64.1</td>
<td>1.15</td>
<td>85.9</td>
</tr>
<tr>
<td></td>
<td>Zn Concentrate</td>
<td>25.14</td>
<td>0.97</td>
<td>55.10</td>
<td>9.9</td>
</tr>
<tr>
<td></td>
<td>Zn Final Tailing</td>
<td>71.80</td>
<td>0.14</td>
<td>1.53</td>
<td>4.2</td>
</tr>
<tr>
<td></td>
<td>Head (Calc.)</td>
<td>100.00</td>
<td>2.46</td>
<td>14.99</td>
<td>100.0</td>
</tr>
</tbody>
</table>

A very marked increase in lead grade was observed without loss of recovery.
EFFECT OF CIRCUIT CONFIGURATION ON METALLURGICAL RESULTS

Circuit configuration is a very important parameter for the processing of ores since it significantly affects selectivity, recovery and equipment cost. It is therefore determined very early in the metallurgical testing of a new ore; there is, however, a fundamental aspect of circuit configuration which cannot be determined during batch testing, and therefore, is somehow neglected during laboratory investigation although its impact on continuous operations can be very important: it is the positioning and quantity of intermediate products recycled in the circuit.

Roughing and Scavenging Stage

In Figure No. 8, the effect of recycling a copper scavenger concentrate to the fresh feed on the rate of flotation is shown. The recycle material was composed of pyrite (40 %), sphalerite (30 %), fine gangue and oxidized pyrite slime (30 %). As a result of the recycling, both selectivity and rate of copper flotation were reduced.

Other ores will allow recirculation of scavenger products to the head of the rougher circuit without harm, as shown in Figure No. 9, where the copper scavenger concentrate contained pyrite (80 %), sphalerite (10 %) and non-opaque gangue (10 %).

Cleaning Stage

To produce a final high grade concentrate, several cleaning operations are usually required, each of which producing highly reactive intermediate products to be recycled at various points in the flowsheet. These intermediate products can also strongly affect the overall metallurgical performances.
Standard procedure calls for a countercurrent recycling of intermediate products in closed circuit, as shown in Figure No. 10. Although this procedure is broadly used, in some cases (massive sulphide ores), the recycling of intermediate products can lead to significantly inferior metallurgy. By opening the first cleaning stage, as shown in Figure No. 11, concentrate grades are invariably improved. The first cleaning stage acts as a second rougher-scavenger, and the cleaner tailing should be a final tailing.

With ores where selectivity is not a problem, higher recoveries can be achieved with a closed circuit cleaning stage. If the recycle products contain a valuable mineral, e.g. sphalerite in the copper circuit, sphalerite recovery in the zinc concentrate is increased when operating in open circuit. Figure No. 12 shows the effect of circuit configuration on the rate of copper and zinc flotation during the various stages; Table No. 2 lists numeric results of open and closed cleaning. These data were generated in a pilot plant investigation on a massive copper-zinc sulphide ore with pre-activated zinc minerals.

**TABLE NO. 2 : Effect of Open Circuit Cleaning on Overall Metallurgy as per Figures 10 and 11**

<table>
<thead>
<tr>
<th></th>
<th>Weight %</th>
<th>Assay %</th>
<th>% Distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Cu</td>
<td>Zn</td>
</tr>
<tr>
<td>Closed Circuit:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Copper Concentrate</td>
<td>5.37</td>
<td>24.0</td>
<td>6.3</td>
</tr>
<tr>
<td>Zinc Concentrate</td>
<td>9.86</td>
<td>0.8</td>
<td>54.3</td>
</tr>
<tr>
<td>Open Circuit:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Copper Concentrate</td>
<td>5.06</td>
<td>26.2</td>
<td>4.2</td>
</tr>
<tr>
<td>Zinc Concentrate</td>
<td>9.97</td>
<td>0.65</td>
<td>55.6</td>
</tr>
</tbody>
</table>
HIGH INTENSITY CONDITIONING TO IMPROVE THE FLOTATION OF ULTRAFINE SULPHIDES

Improving the beneficiation of ultrafine sulphide minerals has become increasingly important in recent years, since more and more processing plants are treating finely disseminated ores.

It is well known that the optimum particle size for the flotation of valuable minerals from massive disseminated sulphide ores lies between 70 and 10 micrometers, as shown in Figure No. 13.

Various theories have been proposed to explain the poor floatability and selectivity of ultrafine sulphide minerals, and relate the poor floatability of slimes to a reduced probability of collision and weaker bubble adhesion due to their small mass, or to the instability of the collector adsorption. Non-specific adsorption of collector due to the high surface energy of ultrafines is blamed for the loss of selectivity.

Most research work has been directed in the past towards understanding the problem and developing chemicals that would improve flotation recovery and selectivity.

Typical rates of flotation of various size fractions of copper and zinc minerals from a massive sulphide ore are shown in Figure No. 14.

The rate of flotation of minus 10 micrometers sulphide minerals is significantly lower than that of the plus 10 micrometers fractions.

Selectivity also is inferior in the finest fractions, as illustrated in Figure No. 15.
To solve the problems of ultrafine flotation, a conceptually new approach was followed at Lakefield, and high intensity conditioning (HIC) was developed as a means of improving the flotation of ultrafine particles from massive sulphide ores that require a relatively fine grind or regrind.

High intensity conditioning has three significant effects on subsequent flotation that account for its uniqueness: (1) The froth after conditioning with collector is heavy and fine particles are aggregated and readily flotable, (2) the selectivity between valuable minerals and gangue slimes is significantly improved so that a higher grade concentrate is usually produced, and (3) flotation performance becomes more sensitive to reagent additions.

**Experimental Method and Equipment**

Experimental testwork with high intensity conditioning has been carried out at both laboratory and pilot plant scales on a number of massive sulphide ores that required fine primary grinding, and on actual plant pulps from commercial operations that treat finely ground massive sulphide ores.

The laboratory conditioning equipment was designed inhouse. Wemco and Denver laboratory cells were modified to act as test conditioning units. These laboratory conditioners consist of a 250 mm diameter, 4 liter capacity tank equipped with baffles and sets of impellers of various designs and sizes.

These impellers were designed for mounting on the shafts of either Denver or Wemco cells. Several pilot plant high intensity conditioning units were tested, including 500 L conditioners with modified baffles and discharge, 5-15 horsepower motors and double turbine impellers of various designs.

During the laboratory and pilot plant testwork, the effectiveness of high intensity conditioning has been examined on ground ore and cleaner feed. Power
input, conditioning time, and additions or collectors and modifiers have been the main variables examined.

Material tested comprises massive sulphide ores containing copper, copper-zinc, lead-zinc, and copper-nickel. Most of these ores required a fine primary grind to a K80 of 65 \( \mu m \) - 40 \( \mu m \) and also a regrind of the concentrates to about K80 of 30 \( \mu m \) - 15 \( \mu m \) before upgrading.

Figure No.16 illustrates the effect of high intensity conditioning on the flotation response of a finely disseminated copper ore assaying 2% Cu, with a gangue composed mainly of pyrite and pyrrhotite. The effect of HIC on copper roughing is very significant; this particular ore represents an extreme case for which the use of HIC is a must, if the project has to go ahead.

The use of HIC has a tremendous impact on the selectivity at both the rougher and cleaner stages, without significant losses of recovery in the total rougher concentrate, as shown in Figures No.17 and No.18.

The major parameters affecting the performance of high intensity conditioning are:

- power input: specific power input (kW/m³), as monitored by the rotation speed of the impeller, plays an influential role in the process, as shown in Figure No.19
- collector level in the HIC: it has usually been observed that the efficiency of HIC is greatly increased when the collector is added into it, as illustrated in Figure No.20
- retention time (energy input): there is usually an optimum residence time, after which performances of the HIC drop sharply, as shown in Figure No.21
Selectivity increase due to HIC, in addition to producing a high grade concentrate, allows also to increase the recovery of other valuable minerals, e.g. that of zinc from a Cu-Zn ore, as shown in Figures No. 21 and 22. While copper grade in the copper rougher concentrate is increased due to HIC, zinc rejection in the same circuit is greatly improved, and therefore, higher zinc recoveries in the zinc concentrate can be expected.

The mechanism(s) underlying the successful application of high intensity conditioning for finely disseminated sulphide ores are not fully understood at this stage. What roles do abrasion and aggregation play and how do they affect the physical and chemical adsorption processes?

Several pilot plant tests both at Lakefield Research and in client plants have been carried out, and others are planned in the near future, to allow Lakefield to better assess the economical impact of HIC and to gather data for scale up and transfer to large scale operations.

CONCLUSIONS

When faced to difficult-to-treat ores, the metallurgist has to rely on new ideas and new procedures to obtain satisfactory solutions.

This paper has summarized some of the progress made at Lakefield Research for the treatment by flotation of oxide and sulphide minerals. Examples are presented of the application of new collector mixtures for the flotation of oxidic minerals such as bastnasite (REO) and phosphate.

New families of depressants to improve the selectivity between sulfide minerals have also been developed by Lakefield Research, and results of the use of one of these families of depressants are presented.
Circuit configuration is an important parameter when designing a plant for the processing of an ore, and the effects of different circuit configurations are presented.

Finally, the processing of finely grained massive sulfide ores has long been a most difficult task for the metallurgist, due to the poor recovery and selectivity achieved on finely ground sulphide pulp when using conventional techniques. A new procedure, developed by Lakefield Research, consists in submitting the finely divided pulp to high intensity conditioning, resulting in increased selectivity and recovery. Some data originating from the application of high intensity conditioning on copper and copper-zinc ores have been presented.
References


FIGURE NO. 1: Flotation of Bastnaesite (REO) at Mountain Pass, Ca.
Plant Flowsheet
FIGURE NO. 2: Laboratory flowsheet developed for the treatment of Bastnaesite ore. New Collector.
FIGURE NO. 3: Simplified flowsheet used for processing sedimentary phosphate ores

Ore

Desliming → Slimes

Fatty Acid Flotation → Tailings

Acid Treatment

Cationic Flotation → Phosphate Concentrate

Silica conc.
FIGURE NO. 4: One-stage flotation of a sedimentary phosphate ore using the new collector.
Figure No. 5: Comparison of Plant and New Collector for the Flotation of P$_2$O$_5$ from the Sand Fraction of a Sedimentary Florida Phosphate Ore.
Figure No. 6: Effect of Various Depressants on the Flotation of Copper from a Massive Cu-Zn Ore.

Figure No. 7: Effect of Cyanide and Depressant DS 22 on the Rejection of Oxidized Pyrite During Lead Flotation from a Pb-Zn Ore.
Figure No. 8: Effect of the recirculation of Copper Scavenger Concentrate to Fresh Feed on the Rate of Copper Flotation from a Refractory Cu-Zn Ore.

Figure No. 9: Effect of the Recirculation of Copper Scavenger Concentrate to Fresh Feed on the Rate of Copper Flotation from a Normal Cu-Zn Ore.
Standard closed circuit recirculation of intermediate products during copper flotation from a Cu - Zn ore
FIGURE NO 11:

Open circuit configuration for the recycling of intermediate products during copper flotation from a Cu - Zn ore
Figure No. 12: Effect of Circuit Configuration on the Rates of Copper and Zinc Flotation During the Various Stages of Copper Flotation.
Figure No.13: Copper and Zinc Recoveries in the Various Size Fractions of a Massive Cu-Zn Ore.
Figure No. 14: Rate of Flotation of Different Size Fractions, Laboratory Data.

Figure No. 15: Copper and Zinc Concentrate Grades in Different Size Fractions. Data gathered during the Survey of an Operating Plant.
Figure No.16: Effect of High Intensity Conditioning on the Grade-Recovery Curves of a Refractory Copper Ore.
Figure No. 17: Effect of Retention Time in the HIC or in the Denver Cell on the Grade of the First Copper Rougher Concentrate from a Refractory Copper Ore.

Figure No. 18: Effect of Retention Time in the High Intensity Conditioner on the Copper Recovery in the Rougher Concentrate from a Refractory Copper Ore.
Figure No. 19: Effect of Power Input (Rotation Speed) in the HIC on the Copper Grade of a Rougher Concentrate at 90% Copper Recovery.

Figure No. 20: Effect of the Percentage of Total Collector Added to the HIC on the Copper Recovery at 26% Cu Grade.
Figure No. 21: Effect of High Intensity Conditioning (HIC) on the Grade of a Copper Rougher Concentrate Obtained from a Cu-Zn Ore.

Figure No. 22: Effect of High Intensity Conditioning on Zinc Rejection During Copper Roughing from a Cu-Zn Ore.