Future Mineral Processing Challenges Based on 45 Years of Applying Science and Engineering to Flotation

AusIMM MetSoc G.D. Delprat Distinguished Lecture

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Structure of Presentation

1. Future needs of an important methodology for mineral separation analysis and process improvement

2. Future mineral processing challenges

3. Key learnings from experience for successfully addressing future processing challenges

Section 1

Future needs of an important methodology for mineral separation analysis and process improvement

A Key Process Development Methodology – Levels of Analysis

Level 1*

Mineral recovery – size relationships** for separations

(size fractions via sieves/Cyclosizer typically)

Level 2*

Mineral recovery – size – liberation class relationships for separations

(Minerals necessary in item 1, not elements, to include liberation data)

Level 3

Can be complemented with surface analysis of relevant minerals in the necessary size fractions/products

*Normally see 3 groups of size fractions – coarse, intermediate and fine

**A. Cameron, D. Kelsall, C. Restarick and P. Stewart, 1971. A detailed assessment of concentrator performance at Broken Hill South Limited, Proc. AusIMM, 240:53-67.

A Key Process Development Methodology – An Application Rarely Utilized in Industry

Valuable mineral liberation level guidelines for:

a) plant feed (no regrinding in following flotation circuit)

b) summed plant exit streams (regrinding in flotation circuit)

Liberation Level*	Possible Separation Quality
<70%	Poor
70-80%	Moderate
80-90%	Good
>90%	Very Good

*Liberation levels are for two dimensional liberation data and defined as the category 98 to 100% + 100% liberated by volume.

N. W. Johnson and P. Munro, 2002. Overview of flotation technology and plant practice for complex sulphide ores, Proceedings Mineral Processing Plant Design, Practice, and Control, SME, 1097-1123.

A Key Process Development Methodology – Future Challenges

Two situations in application of the methodology to ores exist.

1. Normal ores (liberation occurring >15 µm), as for the vast majority of ores.
   - Desirable to have additional size fractions at fine end

2. Difficult ores such as McArthur River and Century (liberation occurring <15 µm) i.e. a minority of ores; the importance of ores needing very fine regrinding may increase in the future.
   - An insufficient number of fine size fractions can be generated and measured for liberation.

A Key Process Development Methodology – Future Challenges with Automated SEM Units at Site

Are there effective duties for automated Scanning Electron Microscopy (SEM) technology at an operating site?

A range of specifications exist e.g. QEMSCAN MineSite is a “ruggedized” model designed for transportation to and use at remote mining sites (elevated dust levels and range of temperature)

- Potential uses being liberation measurements, mineral assays etc.

- Only perform selected duties at the mine/concentrator site?

- Establish broadest size fractions possible/sample not sized for some uses at a mine site?

Section 2

Future mineral processing challenges

(This presentation does not cover rejection of low grade portions of the feed stream early in the processing sequence by a range of methods.)

Use of Liberation Data for Radical Design Directions - More Energy Efficient Plants

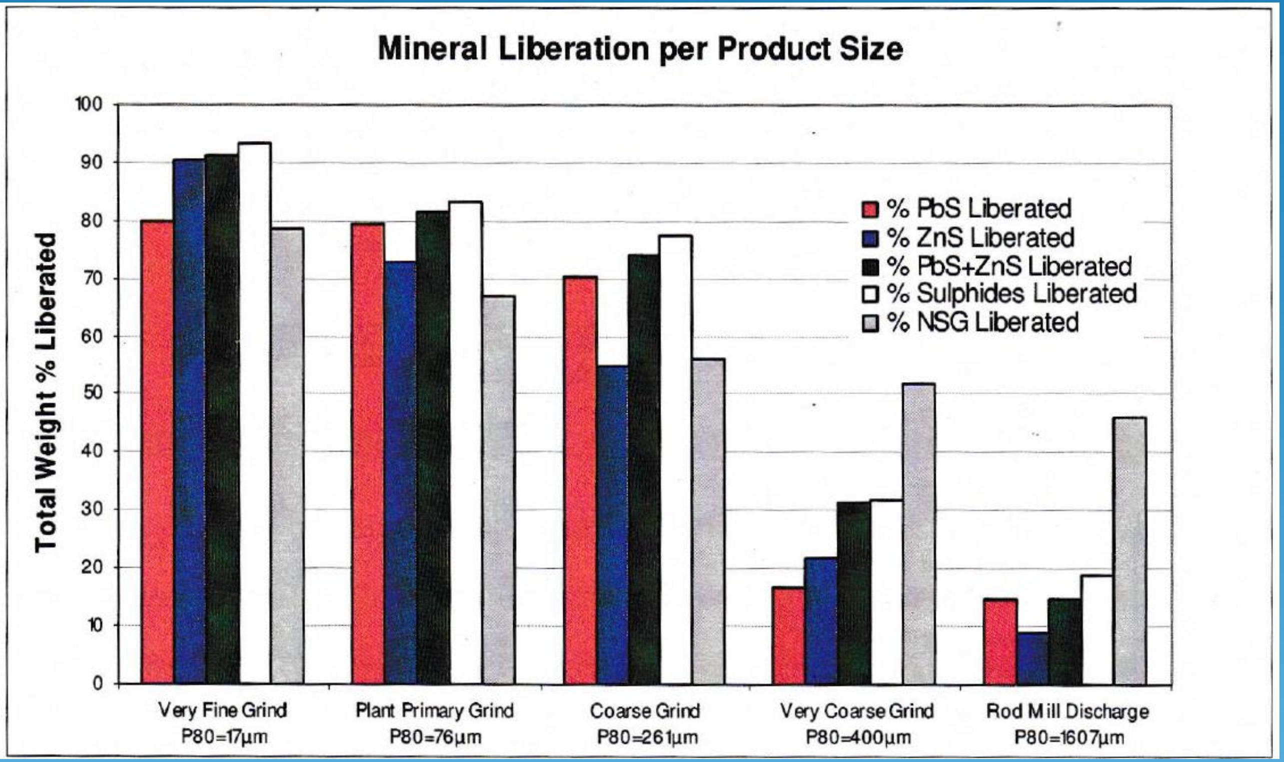
Liberation data can also be used as a cheap tool for recognition of different, sometimes radical design directions.

This approach is rarely, if ever, used in industry for design (time/cost constraints).

The types of outcomes (next 2 slides*) require a demonstration project as the next step.

*From research performed on Mount Isa zinc-lead ore in a PhD Thesis (Zeljka Pokrajcic, 2010. A methodology for the design of energy efficient comminution circuits, JKMRC/SMI/Univ. of Q'ld)

Use of Liberation Data for Radical Design Directions - More Energy Efficient Plants



- Wide range of feed sizes and resulting liberation values (100% class)
- Groupings of sulphide minerals included e.g. PbS + ZnS + Iron Sulphides
- Feed sizing (P80) typically 100 µm
- Note decline in liberation values with increased feed coarseness, as expected

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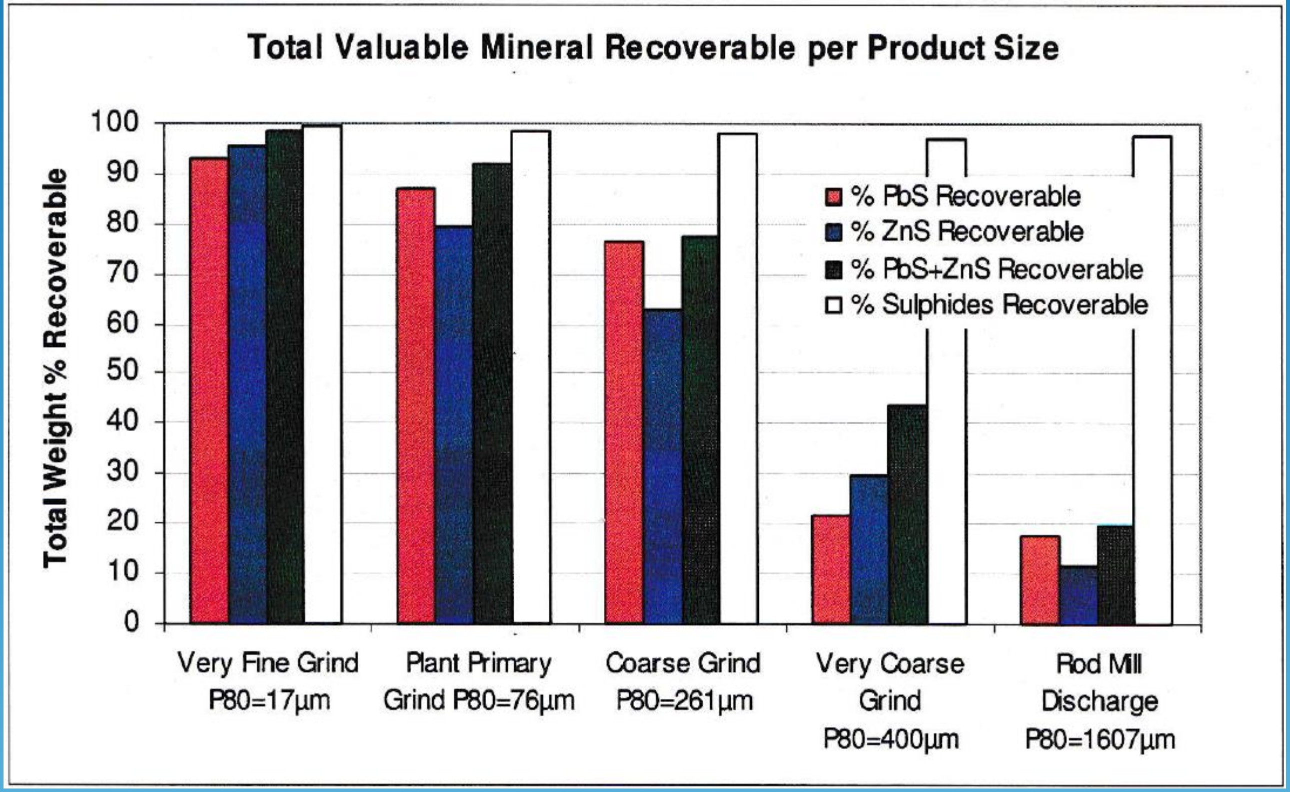
Use of Liberation Data for Radical Design Directions - More Energy Efficient Plants



Y axis: "initially recoverable" category for minerals or groupings (>15% sectional area)
Grouping based on "recoverable sulphides" of high interest (values high at coarse sizes)
Requires improved ability to recover coarse sulphide bearing particles (all sulphides hydrophobic) with a flotation process. Gravity process or combinations also possible.

Use of Liberation Data for Radical Design Directions - More Energy Efficient Plants

Important aspects of initial recovery of valuables at coarser sizes

1. Combined hydrophobicity of all sulphide minerals or of at least two associated sulphide minerals, producing a bulk rougher concentrate (requiring regrinding/separation)

2. Regrinding of the relatively low flow of rougher concentrate, preferable to grinding finer* a much higher flow of rougher feed

*Each halving of rougher feed P80 value requires 42% extra energy.

Future Benefits of Described Approach

Additional Very Important Benefits from Coarser Tailing

a) Assists solid/liquid separation on tailing, including by filtration*

b) Filtration* allows stable and safe "dry stacking" of tailings on surface (no tailings dam failures possible)

c) Allows additional water recycling

* Appearing in overseas designs

Improvement in Concentrate Quality – Future Challenges

Existing Sales Contracts

The "messages" in the current contracts may be out of date.

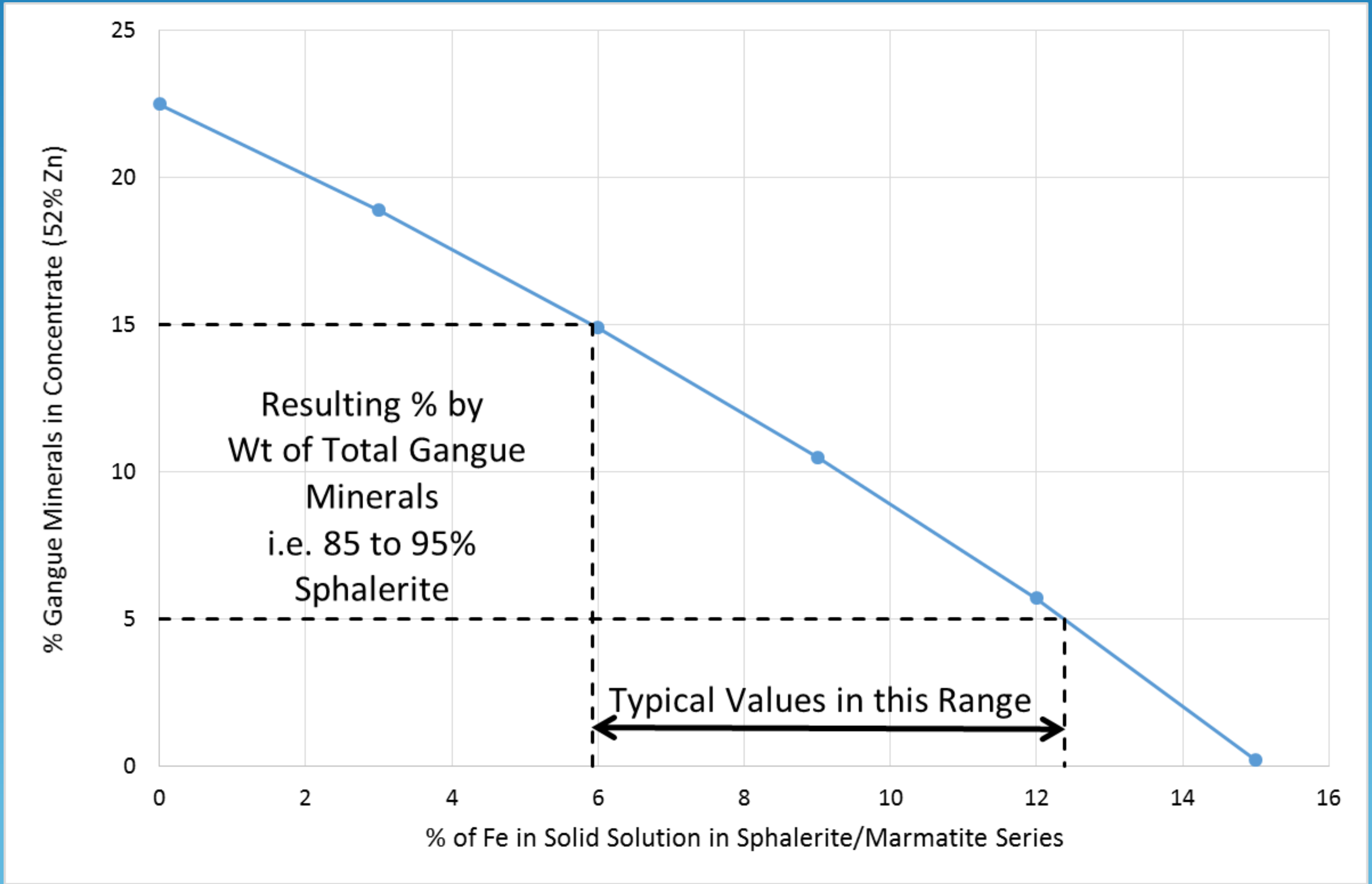
Revised Future Sales Contracts with Increased Incentives for Production of Higher Quality Concentrate*

The challenge will be to improve the plant grade recovery curve and operate at a higher target concentrate grade on that curve.

***Topic for a Keynote Address (P. Munro) at the MetPlant 2015 Conference in Perth**

Scope for Improvement in Concentrate Quality

Sphalerite/Marmatite concentrates (Zn,Fe S) – highest quality sulphide concentrate in the sulphide industry (of the common ones)



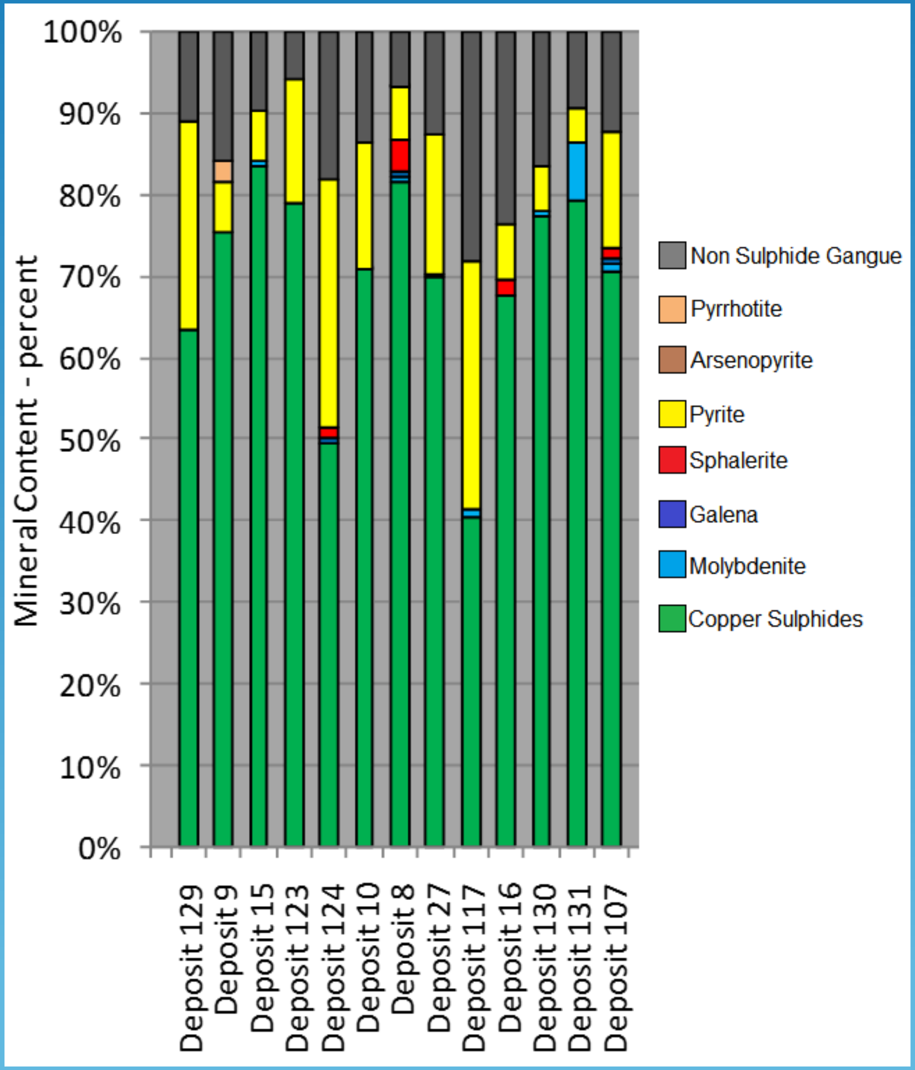
Scope for Improvement in Quality of Concentrates – Copper Concentrates

Various concentrates from ores with >95% of copper in feed as chalcopyrite

Range of 40 to 84% copper sulphides (shown in green) in the concentrates

Note: moderate quality only (lower quality than previous slide)

Data from H. Johnston, Base Metallurgical Laboratories Ltd, Kamloops, B.C., Canada.



Approaches to Improvement in Concentrate Quality

Improve the position of the plant grade recovery curve:

a) improve separation of liberated minerals

b) improve the liberation of the valuable mineral(s)

c) improve in both a) and b)

Note: An extra motivation – removal of As or Sb bearing minerals; future competing technologies likely to be hydrometallurgical.

Loss of Valuable Mineral in Tailing

Differing requirements of the two major particle groups lost (conventional cells) – fine fractions and coarse fractions are the "TROUBLESOME FRACTIONS"

Type of Loss of Valuables	Requirements
-10 µm liberated, dispersed valuable mineral (fine fractions)	a) Elevated turbulence to maximize number of collisions with bubbles b) Collector/reagent addition freedom to raise hydrophobicity
Coarse low quality composites containing valuable mineral (coarse fractions)	a) Just sufficient turbulence for suspension of particles, additional turbulence detrimental b) Collector addition freedom to raise hydrophobicity

Loss of Valuable Mineral in Tailing Future Challenges

All size fractions (fine, intermediate and coarse) processed together (items 1 and 2) or "separately" (item 3)

1. Use of one conventional cell type in a bank e.g. a rougher scavenger bank; tune for coarse or fine fractions or accept compromise tuning. Note: NO FLEXIBILTY

2. Use of two cell types in a bank e.g. a rougher scavenger bank with the two cell types tuned by the manufacturer differently; perhaps one type with a radical design? Note: SOME FLEXIBILITY

3. Provision (plant design stage or retrofit) of two types of separate treatment* for problematic size fractions. Note: HIGH FLEXIBILITY

*G. Heyes and J. Phelan, 1988. The application of separate conditioning to improve zinc metallurgy at Woodlawn Mines, Third AusIMM Mill Operators' Conference, Cobar, 85-89.

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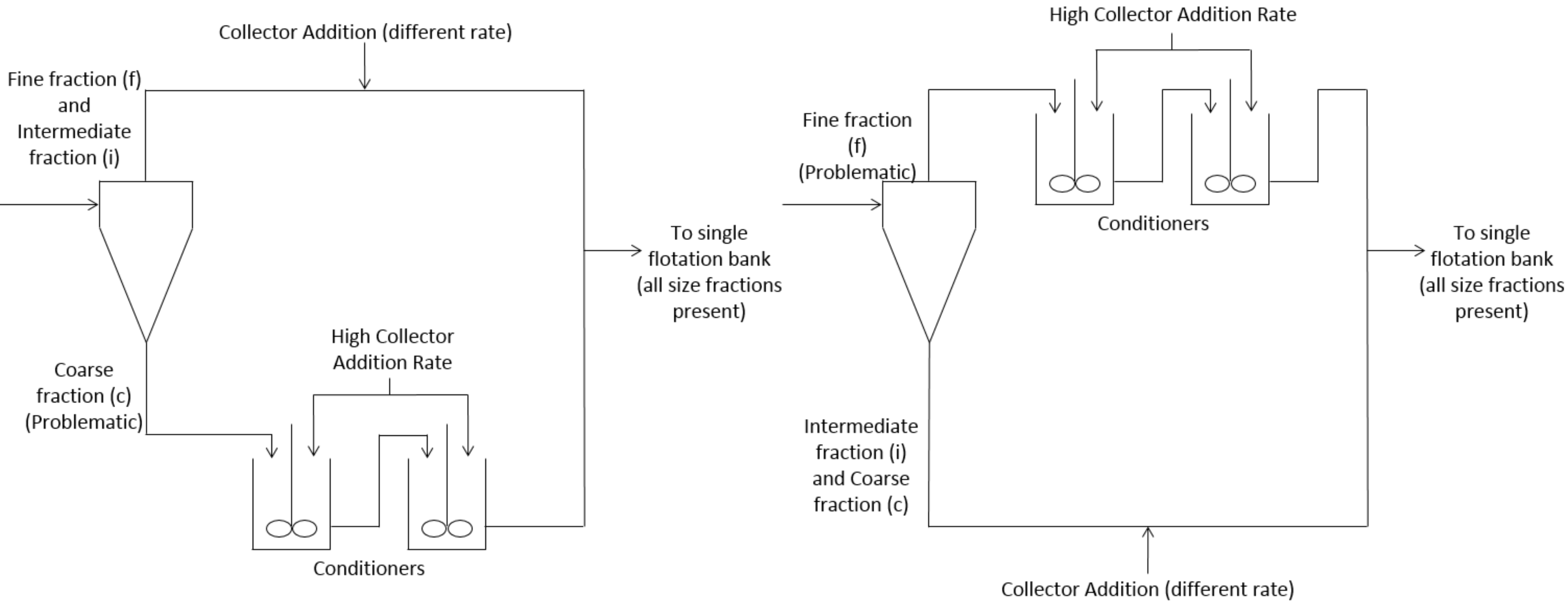
Loss of Valuable Mineral in Tailing Future Challenges

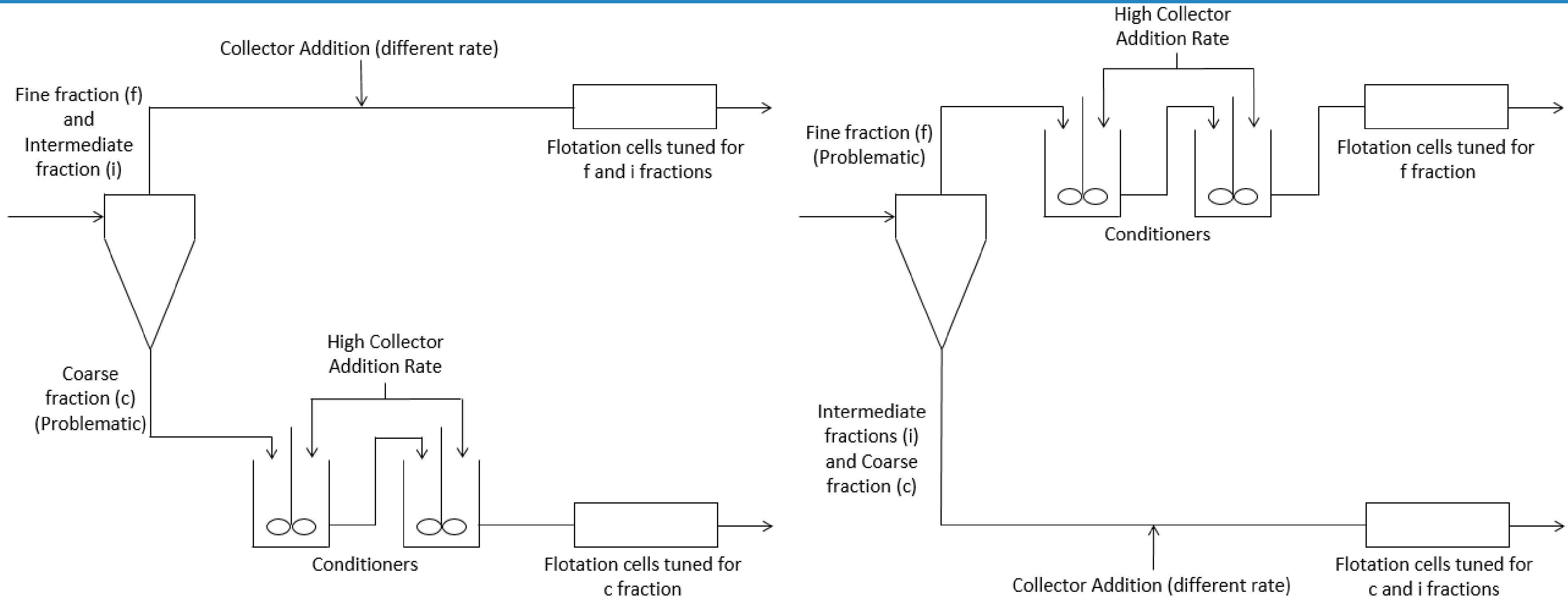
Troublesome size fraction conditioned separately with all size fractions processed in flotation bank together (one or two cell types in bank)



Independent chemical preparation on coarse fraction (case on left) or fine fraction (case on right); no detrimental effect on other fractions

Loss of Valuable Mineral in Tailing Future Challenges

Troublesome size fraction conditioned separately and then treated by flotation separately



Independent chemical conditioning (as in previous slide) +
separate flotation banks (different chemical and physical conditions)

Summary of Future Options

Primary Grinding Sizing/Circuit Type	Improved Conventional Cells	Alternative Cell Designs***
Same sizing & circuit	✓	✓
Coarser sizing, same circuit	✓	✓
Much coarser sizing*, “multiple mineral** basis” & changed circuit	✓	✓

*May include additional options covered in slides 19 to 21

**From the approach in slides 10 and 11 (PhD Thesis of Z. Pokrajcic)

***As a potential example, Hydrofloat technology from Eriez

New Tool – Measurement of Froth Recovery (Future Challenge)

Froth recovery (% of valuables entering the froth region that reaches the concentrate launder) believed to range from 5% to 50% in industrial cells for valuable minerals.

Lowest values in important scavenger cells at end of rougher?

Note - Methods for direct measurement now exist; this new tool is expected to be a major source of valuable new information and insights leading to process improvements.

Problem - It appears that plant metallurgists are:

1. Not aware of this option and its potential usefulness
2. Not aware that external providers can obtain the value or provide instruction on measuring the value

Determination of Dispersion State of a Pulp – Future Challenge

Relevance of Dispersion State of a Pulp

A poorly dispersed pulp results in additional process weaknesses – adhering gangue diluting the concentrate and lowered hydrophobicity of valuables causing losses

Current Situation

The Mineral Industry has no agreed standard procedures for its quantification in a relative or an absolute fashion.

Future Challenge

A standard procedure needs to be developed (one possible application given in next slide).

Determination of Dispersion State of a Pulp – Future Challenge

Size reduction devices with high internal shear now exist for:

a) regrinding to normal and very fine product sizings

b) final stage of primary grinding

Examples are the IsaMill and the Outotec regrinding mill.

Question on an effect "beyond size reduction":

Does a surface cleaning effect equivalent to high intensity conditioning occur in the residence time of such mills?

Initial Paper on Topic for Such Mills:

X. Ye, S. Gredelj, W. Skinner and S. Grano, 2010. Evidence for surface cleaning of sulphide minerals by attritioning in stirred mills, Minerals Engineering, 23, 937-944.

Deliberate Flocculation

Potential applications exist in the literature:

1. Alleviation of <10 μm valuable particle-bubble collision problems by selective flocculation of the valuable particles to produce floccules of a size avoiding this problem.

The step would occur on a fine fraction hydrocycloned from the feed or on a very finely reground product?

2. Alleviation of gangue entrainment in recovered water by selective flocculation of fine gangue particles to produce floccules of sufficient size to avoid largely the gangue entrainment problem.

(Perhaps a complicated method for dealing with entrainment for which other solutions exist in typical systems.)

Pulp Potential in Sulphide Mineral Flotation - Introduction

The important role of pulp potential in collector uptake and the actions of depressants has been demonstrated over the last 50 years (adopted earlier in corrosion, hydrometallurgy and other areas)

The next three slides consider the role of pulp potential:

1. An example of values for a conventional grinding/rougher circuit
2. Description of past/current areas of activity
3. Future needs and challenges

R. Woods, 2010. Electrochemical aspects of sulfide mineral flotation, in Flotation Plant Optimisation (ed. C. Greet), AusIMM Spectrum Series, No. 16, 123-135.

Y. Hu, W. Sun and D. Wang, 2009. Electrochemistry of Flotation of Sulphide Minerals, Tsinghua University Press and Springer, 304 pp.

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Role of Pulp Potential in Sulphide Mineral Flotation

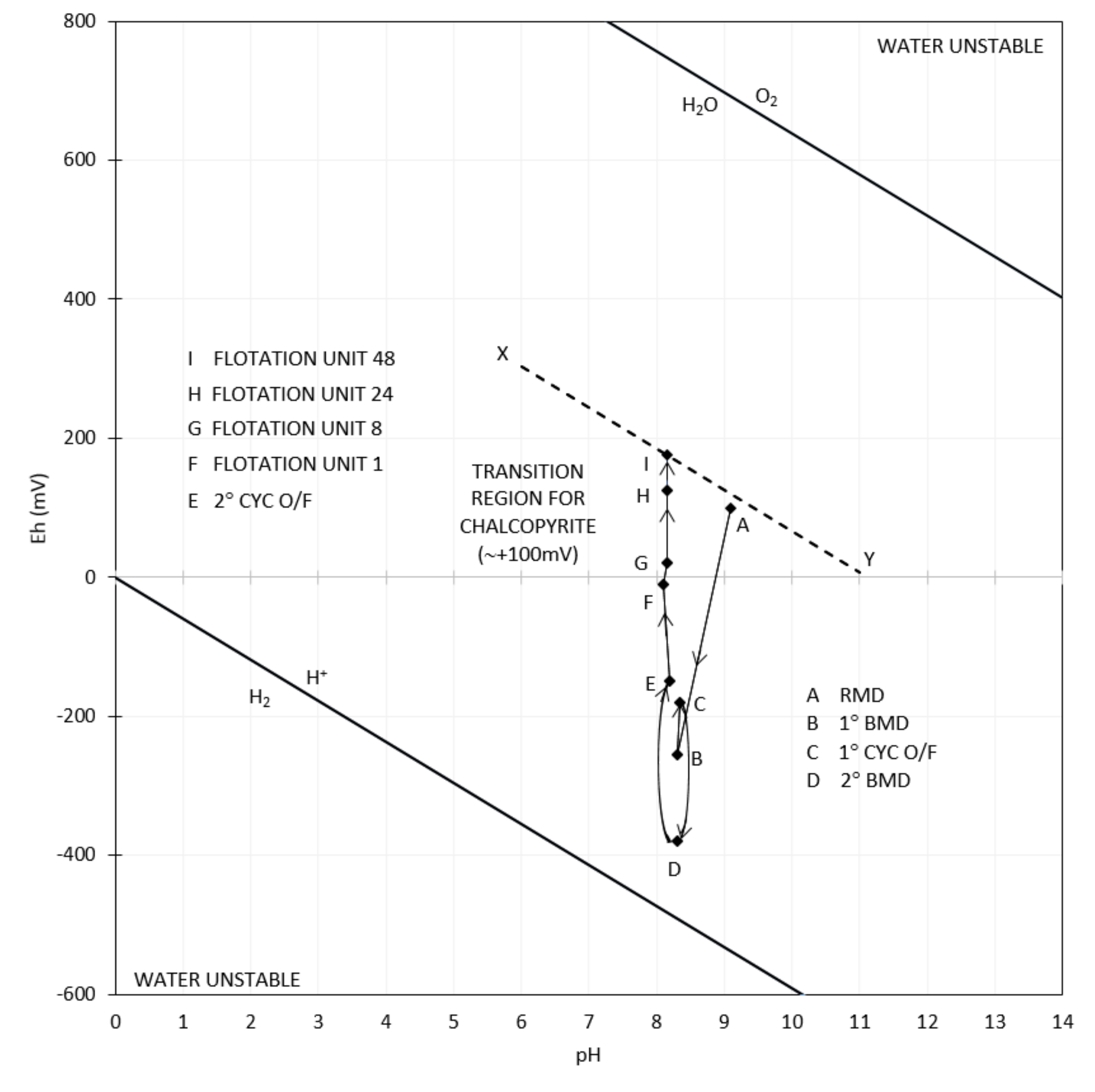

Diagram of pulp potential vs pH from survey measurements at Mount Isa Cu Concentrator

(Pt electrode/reference electrode)

Modified from:

N. W. Johnson, 1988. Application of electrochemical concepts to four sulphide flotation separations, Electrochemical Soc. Conference on Electrochemistry in Mineral and Metal Processing II, Atlanta, May.

Pulp Potential in Sulphide Mineral Flotation – Past/Current Activities

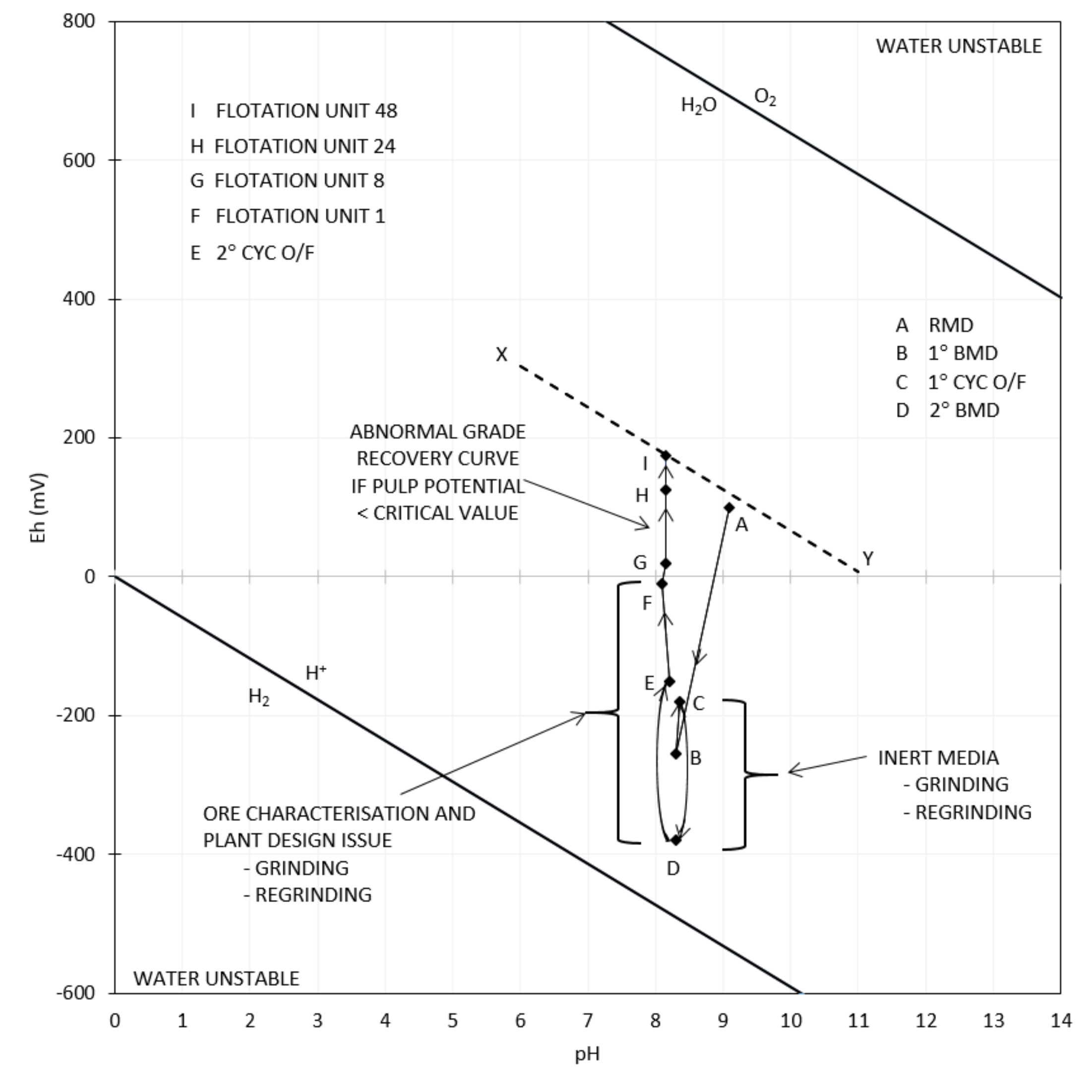

Diagram of pulp potential vs pH for general illustration of past and current activities

Pulp Potential in Sulphide Mineral Flotation – Future Challenges

Evaluate multiple mineral electrodes and pulp potential measurements for:

a) suitable on-line cleaning methods of electrodes to ensure integrity of data over time

b) improved separation efficiency from application of reliable values in a)

Development/operation of new separations in Eh-pH regions away from the equilibrium line X-Y.

Minimization of Use of Water at an Operating Site – Future Challenges

1. Important at an operating site in a region due to existing uses for the population and farming

2. Important for obtaining project approvals in arid areas

3. Important for cost minimization where input water has to be pumped long distances or to high altitudes

Note: Minimization of water use = Maximization of water recycling

General Effects of Recycling Water

Recycling water often increases in the plant the concentration of:

1. Frother (plant must be in control by ensuring some frother addition)
2. Collector species and their decomposition products
3. Other organic species from the tailing dam region
4. Inorganic ions
5. Anaerobic and aerobic microbiological species

From the literature, the effects on flotation are detrimental, in general, with only occasional examples of beneficial effects.

Formal methods for evaluation of the size of the detrimental effects needed (existing plants and during circuit development).

Future Treatment of Recycled Water

1. Will assist maximization of water recycling

2. May improve metallurgical performance

3. Lessens recycled water as a source of plant disturbances

4. Recognize that some common water treatment reagents are used also as flotation reagents; a more effective co-ordinated design of mineral processing and water treatment plants may result at a site

Note: “Water company” to operate such water treatment plants.

Future Treatment of New Water

Low quality new water supply - increased need for water treatment before use in the process

New Water Quality – Australia and surrounding region

Source of Water	Total Dissolved Solid (ppm)
High quality tropical water	100 - 500
Semi-arid water	1000 - 5000
Sea water	35,000
W. Australian bore water	< 300,000

Note: Sewage plant effluent from a regional town/city can have total organic carbon levels > 1000 ppm

Section 3

Key learnings from the past for successfully addressing processing challenges

Requirements for Success

Property	Example
Pressing/urgent need as a precursor	Retention of leases/company government interactions; delays from very fine grained ore (1955 – 1989) for McArthur River deposit; required new regrinding technology (IsaMill – P80 = 7 µm, 1990-1994)
	Initial development of various forms of the flotation process at Broken Hill (mining field faced closure). Major contribution from G. D. Delprat.

Requirements for Success (cont.)

Property	Example
Flexibility in approach	Lower output U/G mine (not pit) for McArthur River project Single zinc-lead concentrate
Wide range of very able engineering skills and sources of feed-stock	Mount Isa operating site for various phases of IsaMill development
Utilization of current “know how” if available elsewhere	Evaluation of washed froth column technology at Mount Isa during 1986 and later installations

Requirements for Success (cont.)

Property	Example
High level strong support from management over several years	McArthur River project - IsaMill technology development
Extra information measured or new insights available	McArthur River project - clearly defined problem by use of detailed liberation data based on new Mount Isa analysis system (mineral recovery/size/liberation)

Conclusions – Future Challenges

Future needs/challenges of an important methodology (based on mineral recovery/size/liberation data) for mineral separation analysis and process improvement

1. Increase the technical application of the methodology, particularly for understanding the contribution of each grinding step to the total liberation.

2. Develop routine liberation measurement on additional fine size fractions.

3. Establish the effective applications of an automated SEM at an operation.

4. Demonstrate the innate value of such process information for a wide range of uses, making it non-discretionary in the management system.

Conclusions – Future Challenges

Future mineral processing challenges

1. Increase recovery of coarse low quality composites with some valuable mineral using improved conventional cells and other types of cells with:

   a) feed to rougher at current feed sizing values

   b) feed to rougher deliberately at <u>moderately coarser</u> sizings than now

2. Use liberation data in unconventional ways for the design of energy efficient separation circuits, utilizing 3 themes for <u>greatly coarsened</u> feed sizings for some ores*:

   a) hydrophobicity from multiple sulphide minerals

   b) techniques of separate conditioning/separation (slides 19-21)

   c) matching of latest/future cell designs to particle properties

*Note: Demonstration project(s) needed (pre-competitive basis?)

Conclusions – Future Challenges

Future mineral processing challenges

3. Utilize the resulting benefits from items 1 and 2 in related areas
   - assisting solid/liquid separation on tailing, including by filtration
   - facilitating safe "dry stacking" of tailings on surface
   - allowing additional water recycling

4. Utilize froth region recovery measurements in process improvement.

5. Develop and utilize a standard procedure for measurement of the state of dispersion of a pulp.

Conclusions – Future Challenges

Future mineral processing challenges

6. Evaluate/utilize multiple mineral electrodes and pulp potential measurements for:
   a) on-line cleaning of electrodes to ensure integrity of data over time
   b) improved separation efficiency using reliable measurements via a)
   Develop and operate new separations away from the equilibrium line.

7. Maximize water recycling assisted by treatment of the recycled water*; extend the treatment to low quality water input water if warranted.

*Aided by formal testing methods for detrimental effects from recycling.

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