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Non-recoverable metals – do you know how much you have?

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When metal prices are high, one means of increasing ore resources is through the introduction of lower cut-off grades. Unfortunately, the cut-off grade definition is not always a simple calculation of value of elements, operating costs and assumed recovery. We can all be caught off guard with a surprising increase in the proportion of non-recoverable metals – thereby causing significantly lower recoveries than originally planned. Ultimately, large investments for increased capacity may prove to be unprofitable.

In the critical production areas, ore resource estimations should be based on mineralogical and metallurgical characterisations of the ore, not just on the total grade of valuable elements. Such estimations then ensure that the proportion of non-recoverable metals is better understood. This information is obviously crucial at the ore evaluation stage.

A classical example of this type of analysis is with nickel ores. When evaluating nickel, for instance, in addition to the total overall analysis, quantitative analysis of non-recoverable grades ensures a more reliable basis. Apart from setting more accurate expectations and budgets, benefits in analysing non-recoverable nickel can also be seen in the ore processing.

Advance knowledge of the distribution of nickel between different carriers enables accurate estimation of nickel recoveries and concentrate grades. Realistic processing targets can be set for flowsheet development and future production. Reasons for nickel losses to the tailings may then ensure a more scientific explanation other than *'it was too fine/too coarse/or the metallurgist was having an off-day'*.

Flotation and grinding obviously have their own influence on recovery, but this article deals more with the inherent mineralogical characteristics and the benefits of analysis of non-recoverable nickel.

What is non-recoverable nickel?

In nickel flotation there are two main types of non-recoverable nickel: (1) non-sulphide nickel-bearing minerals and (2) difficult particle sizes of sulphide nickel.

(1) Non-sulphide nickel - the proportion of non-sulphide nickel can be quite considerable, especially in disseminated sulphide nickel ores. In the low-grade ores, a significant part of the total nickel is

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bound in silicate minerals, such as olivine, serpentine, talc, pyroxenes and amphiboles. The trace nickel content of olivine and its alteration minerals is generally from 0.1% to 0.3%, but there have been cases where the content is even more than 1%. Thus, the highest non-sulphide nickel grades are usually found in disseminated ores hosted by dunite, peridotite, serpentinite or talc-bearing rocks.

(2) Difficult particle size - sulphide nickel locked as very fine grains in gangue minerals is defined as non-recoverable. This is due to the fact that the required grinding power to liberate the particles would not be economical.

Fine-grained pyrite-millerite dissemination in serpentinite is shown below as an example. Primary disseminated coarse sulphide has been shattered by secondary antigorite laths. From this type of ore, poor sulphide liberation is expected after grinding.

Non-recoverable nickel analysis

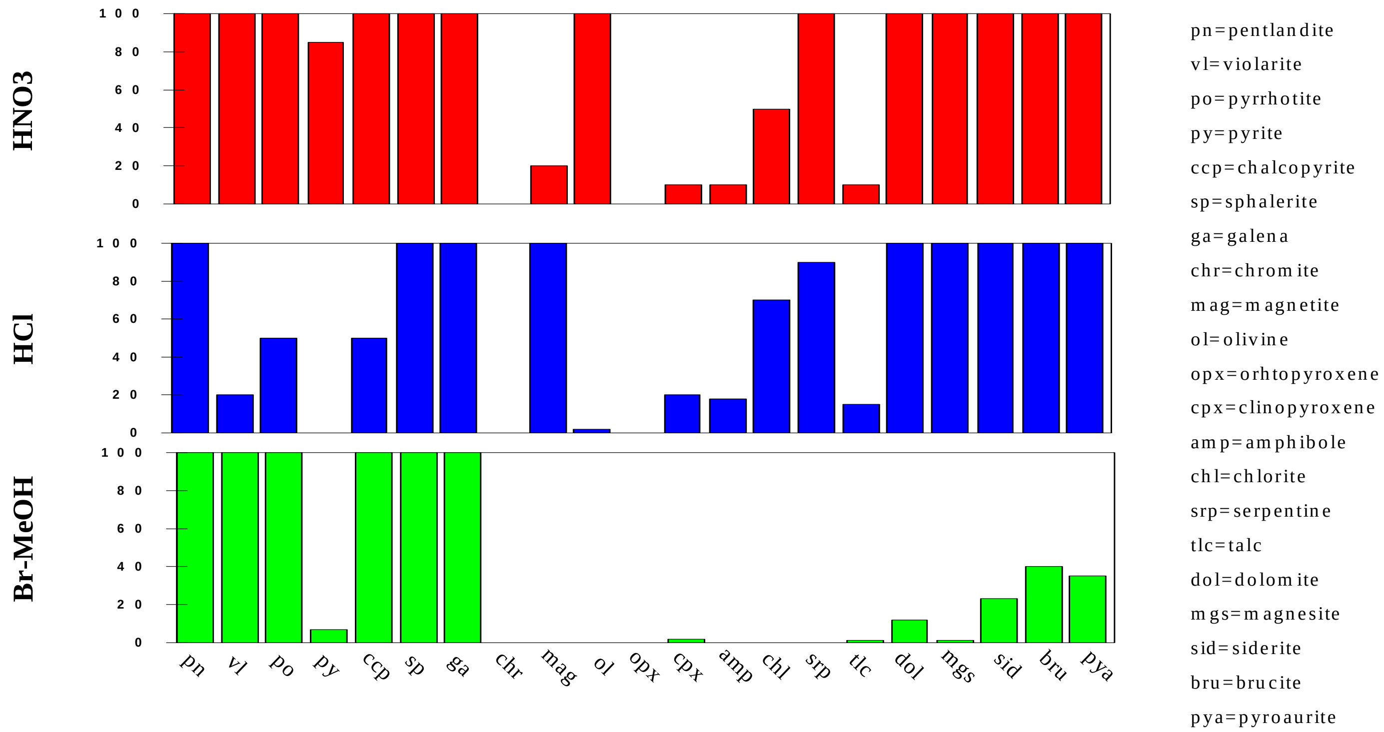
Outokumpu Research has studied the solubility of Ni-minerals and common gangue minerals in mineral acids and developed a routine methodology for the determination of non-recoverable nickel. In the analysis the following three grades of nickel locked in gangue minerals are determined – (1) total nickel (2) non-sulphidic nickel and (3) sulphidic nickel.

Analysis utilizes highly selective bromine-methanol leaching (see table on next page) which dissolves the common sulphide minerals associated with typical nickel ores apart from pyrite. Also, the solubility of non-sulphide minerals is minimal with bromine-methanol. When there is knowledge of gangue mineralogy of the particular ore, simple chemical analyses give an accurate estimation of non-recoverable nickel.

In the evaluation of disseminated nickel ores typically non-sulphide nickel analyses are performed on the drill core samples along with the base metal assays. Detailed analyses are carried out with the feed samples prepared for the processing tests and milled into flotation fineness. This provides important information, especially when the sulphides occur as a very fine-grained dissemination in silicates. Analyses should be done by size fractions and in flotation fineness to optimise particle size distribution in the process.

In one particular case study, non-recoverable nickel was analysed from flotation feed. The histogram shows the effect of ore characteristics on the recovery. Minimum nickel loss with the selected particle size distribution is about 13%, coming mainly from the non-sulphidic nickel (11%) and the rest (2%) is as locked sulphide

Primary disseminated coarse sulphide has been shattered by secondary antigorite laths



Extraction of nickel from the most common minerals of nickel sulphide deposits using different solvents: HNO3 = nitric acid, HCl = hydrochloric acid and Br-MeOH = bromine-methanol

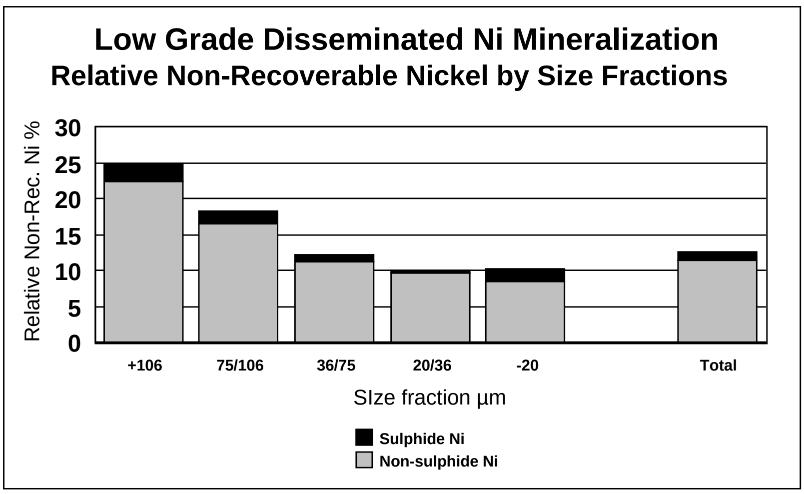
nickel particles. Maximum recovery in the example case would be 87% of total nickel and 98% of the sulphide nickel, but poor flotation conditions would affect the recovery. The highest relative Ni loss is in the coarsest size fractions. Total nickel analysis of the bulk tailings sample alone does not explain the real reasons for nickel losses. It is through analyses of non-recoverable nickel that possible reasons for Ni losses can be concluded. These reasons could include grinding which was too coarse or too fine, high non-sulphide nickel or poor chemistry in flotation.

Summary

The understanding of both recoverable and non-recoverable mineral behaviour is critical to determining the economic viability of any given ore type.

In some cases, such as in nickel ore processing, this understanding may require the use of chemical analysis methods that target different mineral types.

Analysing feed and tailings streams across various size fractions is recommended.



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Frothing at the thickener

Brad Garraway

There is no question that the entrainment of finely divided air in thickener feeds can cause significant problems in a thickener's operation, especially in mineral processing plants. This is particularly the case with thickening of flotation concentrates, in which air bubbles are strongly attached to the mineral particles and are difficult to remove. Resulting particles rise with the air bubbles to the thickener surface, eventually travel into the thickener overflow collection and hence into plant process water. High solids carryover can lead to a direct loss of mineral product and, if the product settles in process water tanks and ponds, the recovery of this product by means of intermittent dredging or clean-out operations is usually expensive and unreliable.

Solutions

There are various solutions to the problem of froth in thickeners.

1. Froth rings or baffles

Many concentrate thickeners are fitted with froth rings or baffles as standard. This helps alleviate the problem to a certain degree but is not an overly effective solution on its own.

Froth baffle & peripheral sprays

2. Peripheral sprays

The sprays are fixed to the thickener's periphery and spray the froth away from the overflow launder, causing the froth to move towards the centre. This method simply moves the froth to another location as it often fails to 'knock' it down. Particles can then build up in the process water, causing the sprays to block and providing real maintenance headaches. On the plus side, peripheral sprays are relatively simple to implement but, unfortunately, are not overly effective.

Rotating boom

3. Rotating boom, fixed sprays on bridge

As the boom rotates through the froth, the intermittently positioned sprays on the bridge hit the froth. This solution can be more effective than peripheral sprays alone but is very much dependent on the correct spray type and operating pressure ie too large a spray and gushing ineffective jets ensue, too small a spray and there is no effect on the froth. A fine mist often surrounds the thickener circuit, resulting in OH&S considerations, amongst others.

Froth skimming

4. Froth collection/skimming, integrated with boom

This more sophisticated system moves the froth via the rotating boom, skims and then removes froth from the thickener surface. This is the most effective of all of the traditional solutions.

Once the froth has been skimmed, however, a new problem has been created – namely, how to deal with the recovered froth? Once it has been collected – how should it be handled, collected, pumped?

All of the above play a part in reducing the amount of solids carried over in the overflow. Many froths, however, are very stable and can persist despite these measures. In the worst cases, a thick froth layer forms, building up to a depth greater than the froth ring, and hence flows over or under it. Blockage of the overflow weir and launder can ensue and hence affect the clarification performance by cutting off sections of the overflow handling system. The formation of a froth layer on the thickener also makes it more difficult for the operator to monitor the clarification performance.

5. Froth deaeration

Froth deaeration is the only solution which tries to resolve the problem before it enters the thickener. The use of stilling wells on the thickener feed has been partly successful in avoiding heavy frothing and has been common in the coal industry. In paper pulp operations, both cyclone and vacuum deaeration has been used to remove air from fibrous pulp, which is critical in the papermaking process. It is only in the past few years that a technology for the deaeration of mineral slurries has been developed.

Frothbuster®

Frothbuster® was developed by Outokumpu to reduce the problem of froth before it enters thickener duties. It is installed int the thickener feedline, from where it detaches air bubbles adhering to the concentrate. Air bubbles are removed from the feed stream, allowing a deaerated feed to the thickener feedwell.

As froth deaeration alleviates the problem before it enters thickening duties, benefits can include: reduced particles in process water, no

Frothbuster®

'Before' deaeration

'After' deaeration

need for maintenance/removal of solids build-up in process water tanks and ponds, and improved flocculation as thickener performance is optimised (as it no longer has to deal with the froth problem).

In order for the deaerator to operate optimally, there are some fundamental design requirements:

1. Feed pressure should be around 100kPa.

2. Feed density should be at 15% w/w or less. The best means of achieving this is to recirculate the thickener overflow to give a feed of 15% w/w or less.

3. A highly aerated reject flow from the deaerator needs to be dealt with and either sent back to the feed pumps or float circuit or forward to the product storage tank. This aerated reject flow represents approximately 3% of feed volume flow.

4. The feed circuit should be designed to ensure Frothbuster® operates optimally with all feed streams reporting to it so that they are treated by the deaerators. This deaeration technology can be integrated into a plant circuit of either a new plant as problem prevention or as a retrofit to resolve an existing one. It suits a range of applications including zinc, gold, copper and nickel processing. It would also be useful in other plants where entrained air is an issue, such as in calcium carbonate plants.

Conclusion

Froth in thickeners is a problem, which can cause many headaches. There are many options to minimising this problem. Solutions such as spraying or skimming the froth vary in their effectiveness, but can result in other issues, such as maintenance or OH&S arising. Whilst such solutions try to deal with the froth once it has entered the thickening circuit, froth deaeration alleviates the problem before thickening duty commences. There are many benefits to solving the problem before it becomes one, including cost, lower maintenance and optimised performance.

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Flotation – how's your lip length?

Andrew Okely

Historically, flotation circuit designers have used a combination of the required residence time of the pulp in the cell and the froth lip loading to determine the number and size of flotation cells required for each duty. The required residence time has been and still is determined through a combination of testwork and scale-up factors. Froth lip loading cannot be determined in a laboratory, as the froth is scraped during the test and thus does not exhibit natural behaviour. The value is generally "checked" via calculation to see if a given maximum value will be exceeded by the cell selection. This maximum number is in fact one of those long-standing rules of thumb, which have their basis in practical experience. In the case of lip loading (tonnes of concentrate per meter of froth lip per hour) the accepted maximum range is 1.0 to 1.5 t/m/hr.

As the understanding of the flotation process has increased, the significance of the rate of recovery of material from the froth phase has become a focus for the flotation circuit designer. The old lip length calculation will no longer suffice as a method of determining whether the cell selection is suitable to optimize the froth recovery for a given duty.

The new areas of interest are the froth-carrying rate, concentrate enrichment ratio, froth transport distance and the concentrate particle size distribution. The impact of each of these froth characterization factors on froth recovery is difficult to simulate in the laboratory cell so a new set of "rules of thumb" have come into existence. This article will look at each of these factors and provide some basic guidelines to consider when specifying flotation circuits.

Froth carry rate

The froth carry rate is defined as '*the dry tonnes of concentrate removed from the cell per square metre per hour ($t/m^2/hr$)'.* Dividing the total dry concentrate tonnes to be recovered per hour by the froth carrying rate will provide the required froth surface area. The froth carrying rate varies with ore type, head grade and flotation duty (rougher, scavenger, cleaner). Thus it is necessary to look at all these factors before selecting a design carry rate.

Typical design ranges are given in table 1 below. These values are indicative and generally safe design parameters. However, successful operations with carry rates outside these ranges are not uncommon.

Duty	Typical Carry Rate $t/m^2/hr$
Rougher	1.0 – 1.5
Scavenger	0.3 – 1.0
Cleaner	1.0 – 2.0

Table 1 – typical design ranges

Enrichment ratio

The enrichment ratio is defined as '*the ratio of concentrate grade over feed grade for the metal of interest*'. This ratio is linked to the froth carry rate described earlier via the minerals grade recovery curve. The relationship is generally exponential in nature with increasing enrichment ratios leading to lower carry rates. A typical example can be seen in figure 1.

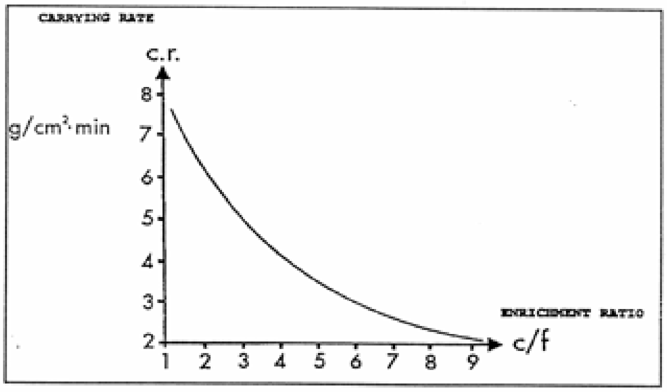

Figure 1 – Determination of carry rate for low enrichment ratio values (1 – 10)

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This relationship can be understood in practice by considering how the enrichment ratio is generally increased in a cell. Typically when the operator wants to increase the concentrate grade (given a fixed feed grade) he or she would decrease the air and/or increase the froth depth. Both of these actions will reduce the rate at which froth is recovered and thus reduce the carry rate.

Froth transport distance

This is defined as '*the maximum distance any given particle in the flotation froth has to travel to reach the froth collection launder and discharge the cell*'.

The development of very large flotation cells has led to an understanding of the relationship between particle drop-back from the froth phase and the froth transport distance. In principle the longer the distance, the greater the particle drop-back, all other parameters being equal. Many properties of both the particles and the froth will impact the rate of drop-back. However, in general, froth transport distances up to 1.2m are acceptable. Very coarse concentrates generally benefit from shorter distances whilst finer concentrates which form tight froths can benefit from longer distances and more drainage time.

Particle size of concentrate

Particle size of the flotation feed and liberated mineral size impact on all aspects of flotation including froth handling. In general, the coarser the concentrate, the shorter the transport distance should be but the higher the carry rate of the froth. Extremely fine concentrates may have inherently low concentrate carry rates as a result of the particle to bubble surface area becoming a limiting factor but generally these situations see very stable froths and can support larger transport distances. By combining an analysis of the froth carrying rate, enrichment ratio, froth transport distance and

An example of too much froth lip length

concentrate particle size, it is possible to select flotation cells which provide the right combination of pulp residence time, froth surface area, froth transport distance and, yes, froth lip length. Analysis of the lip length is how lip loading is calculated – but it doesn't drive the selection process, it's an outcome of it.

Conclusion

This brief discussion highlights the increasing complexity of successfully designing a flotation circuit. The almost exclusive use of large flotation cells has forced us to look beyond the launder lip loading and into the actual behaviour of the froth phase itself. The information above will help to guide those deciding upon the number and size of flotation cells required but it is not a substitute for experience and looking at what is actually working in the field.

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