INDUSTRIAL APPLICATIONS FOR COLUMN CELLS AS ROUGHERS

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ABSTRACT

The installation of large diameter flotation columns is now being regularly considered by designers of new flotation projects. The level of reliability of these large units has reached a point where the equipment can be selected with a great deal of confidence. Large diameter columns offer significant cost advantages per ton of capacity when compared to smaller units.

Although the majority of new column cell installations continue to be for cleaning service, an increasing number of projects are specifying column cells for roughing and scavenging duties. Substantial savings in capital and operating costs can be achieved by utilizing column flotation technology.

In the past five years, several new flotation plants have been built using only column cells. Other plants have undergone complete conversions from total mechanical flotation circuits to total column flotation circuits. Column flotation may, however, not be suitable for all rougher applications. The process of evaluating a potential application, the expected economic benefits, and the methodology of implementing rougher column processes are discussed. Some operating data are also presented.

INTRODUCTION

Column flotation technology was introduced to the market place about thirty ago years as a device capable of producing concentrates that were lower in impurities than those produced by other types of flotation machines. The ability to operate columns with significantly deeper froth beds and the provision of a froth washing system were the main reasons cited for the improved metallurgical performance.

Column cells are now well accepted by the industry for cleaning applications, but there continues to be considerable skepticism about their use as roughers. This skepticism is not totally unfounded. There have been several documented cases of rougher installations which fell well short of predicted metallurgical performance. The reasons for the shortcomings vary from case to case, however, they can be generally attributed to incorrect sizing, inappropriate application and or a lack of understanding of how column cells must be integrated into an existing plant or new project.

In recent years there have been many successful installations world wide confirming that, with proper care, the benefits offered by the technology can be realized over a much wider range of applications.

Columns may not be the best choice for every application. This paper discusses some of the important considerations that designers must take into account when contemplating the use of columns as roughers.

FACTORS TO CONSIDER WHEN CONTEMPLATING THE USE OF COLUMNS

The mineral processing engineer is faced with many choices for the selection of processes and equipment when designing a new concentrator. For every unit operation, there are a number of options to be considered. For example, for grinding there are the choices of autogeneous, semi-autogeneous or rod mill/ball mill circuits. For de-watering circuits, there are many options, including disk filters, drum filters, belt filters and a variety of pressure filters to be considered. Similarly, for the flotation circuits there are many different types of machines available for use including conventional mechanically agitated cells, column cells, pneumatic cells, flash flotation cells etc. In many instances, characteristics of the ore will dictate whether or not certain methods can be applied. In other cases, economic considerations and personal preferences of the operators will prevail.

During the design process, the engineer responsible for the selection of equipment will use a systematic approach to review and justify the selection based mainly on the following criteria:

- Technical benefits / concerns
- Economic considerations
- Analysis of technical risk versus economic benefits

<u>Technical Justification</u>

The technical justification is the most important and is often the most difficult evaluation to make properly. The evaluation must go beyond a direct comparison of mechanical cells and column cells operating in a similar circuit. Column cells often provide metallurgical benefits (such as greater selectivity) which can be taken advantage of to simplify the flowsheet. Conversely, variations in the composition of the ore, liberation characteristics or operational variations could adversely affect the metallurgical performance if these items are not factored into the design.

When considering the use of columns as roughers, the following items should be contemplated, in order to assess the benefits and possible risks associated with using columns in the rougher stage.

Metallurgical Benefits

Metallurgical benefits can be derived in a number of ways. In some cases the metallurgical benefits may be obvious. Improved concentrate grades, improved recoveries and reduced reagent consumption are some of the benefits attributed to column cells over the years.

In other cases the benefits may be less clear. With some ores, for example, it is possible to recover a portion of the valuable mineral into a high grade concentrate directly from the rougher stage, thereby reducing the size of the subsequent treatment stages.

In order to fully take advantage of columns, it is necessary to design the flowsheet with some specific objectives in mind. It is also important to understand the implications of additional dilution due to the wash water addition and the potential for the accumulation of slimes within the circuit.

Mineralogical Considerations

The mineralogical characteristics of the ore play an important role in the design of the circuit. It is necessary to know details about the homogeneity of the ore, variations in mineralogical composition and the effects that these variations have on the liberation characteristics. Experience has shown that liberation of the ore is the single most important factor in determining the suitability for using columns as roughers. It has often been stated that column cells are less effective at recovering coarse particles than mechanical cells. This is not necessarily true. If the minerals are well liberated, the recovery of coarse particles by column flotation can be as good as, and in some cases better, than the recovery achieved by mechanical cells.

The selective nature of columns makes it difficult to recover mixed particles, particularly if the valuable constituents occur as small inclusions in coarse grains of gangue. Depending on the relative proportion of liberated particles to mixed grains, and the required level of recovery, it may be prudent to include a stage of mechanical cells as scavengers.

If the feed grade to the flotation circuit is highly variable, it is essential that the circuit be designed to handle the full range of expected conditions. A common mistake has been to base the design on the average feed rate and grade without a provision for variations. This problem is most frequently encountered in small open pit operations where, due to mining equipment constraints, grade control can be difficult. If the magnitude of feed variations is known in advance, the circuit can be designed to accommodate the changes.

Need for Conditioning

It is common practice to add reagents directly to mechanical cells. The agitation provided by the impellers is effective at dispersing the reagents in the pulp. The quiescent nature of the flotation column does not make for an ideal environment for direct reagent additions. Pre-conditioning of the feed is recommended particularly when it is necessary to impart energy to the system for dispersion of slimes, scrubbing mineral surfaces or otherwise preparing the minerals for flotation. It is not always necessary to provide an agitated tank as a conditioner. Depending on the specific conditioning requirements, some operators have successfully used in-line static mixers to provide the necessary dispersion and mixing.

Selectivity Vs. Recovery

Columns are often discounted as roughers because of the beliefs that a) mechanical cells will provide a higher level of recovery, and, b) higher recovery provides more revenue than higher grades. For simple ores, this is may be true. For more complex ores containing impurities which translate into additional treatment and refining charges, or for mines located in very remote regions, the benefit of being able to produce high grade concentrates even at the expense of a slight reduction in recovery, may make economic sense.

Economic Justification

The magnitude of economic benefits including the savings in capital and operating costs can vary significantly from project to project and will depend on a number of factors. Some of the most important factors are listed below:

Improved Metallurgy

For some processes, the use of column flotation has been shown to provide higher levels of recovery or better concentrate grades, thus contributing significantly to the economic viability of the project.

Reduced Capital Costs

The savings in capital cost will depend on the size and complexity of the circuit, the location of the plant and to a lesser degree the level of automation desired. Typical savings can range from 10% to 40%. For small and simple plants, the relative cost of the flotation plant is small in comparison to other sections of the concentrator and therefore the savings in capital cost may insignificant. For large projects the savings in capital can be substantial. Not only is the cost of the equipment less, but the costs of ancillary equipment, electrical services and building size are also reduced. In subtropical climates, it may be possible to eliminate a building entirely.

When comparing the cost of a column plant versus a conventional plant care should be taken to evaluate the level of instrumentation that is being proposed. Column cells generally have a greater degree of automation than conventional cells. The level of automation can be classified into two basic categories; stabilizing controls and optimization controls. The control system should be matched to the duty that the column will be performing. It is generally recommended to begin with a good basic control system and to add optimizing controls as the need arises.

Operating Cost Savings

Operating cost savings can be realized from reduced power requirements, reduced maintenance costs and in some cases reduced reagent consumption.

- Power costs are typically 50% lower than an equivalent mechanical flotation circuit.
- Column cells have very low maintenance requirements and low inventory requirements.
- Reagent savings depend on the nature of the ore being treated and the reagent scheme being utilized. The most significant reductions usually occur with depressants, where it is possible to use wash water to lower impurity levels.

ANALYSIS OF TECHNICAL RISK VERSUS ECONOMIC BENEFITS

Assuming that all of the selection criteria have been satisfied, the technical risk of using columns in rougher applications will be low. In any event, it is prudent to conduct some sensitivity analysis on the economic effects that variations in grade and recovery would have in relation to the derived benefits. This type of analysis is more applicable to cases were columns are being considered as part of a plant expansion or modernization rather than a new project since accurate production data are available for comparison.

Industrial Column Rougher Circuits

Column roughers are being used successfully in a number of plants around the world. Descriptions of various applications in zinc, fluorspar, phosphate, copper, lead, iron ore and glass sand have been described in the literature.

The following examples describe two processes where column cells have been successfully implemented as roughers. For both of these plants, column cells are the only type of flotation cells being used.

Example 1 - Reverse Silica Flotation From Iron Ore

A typical process flowsheet used by many South American iron ore producers is shown in Figure 1. High grade hematite ore is crushed and classified into three main product categories; lump ore, pellet ore and sinter feed. Until about five years ago, the fine iron was routinely discarded.

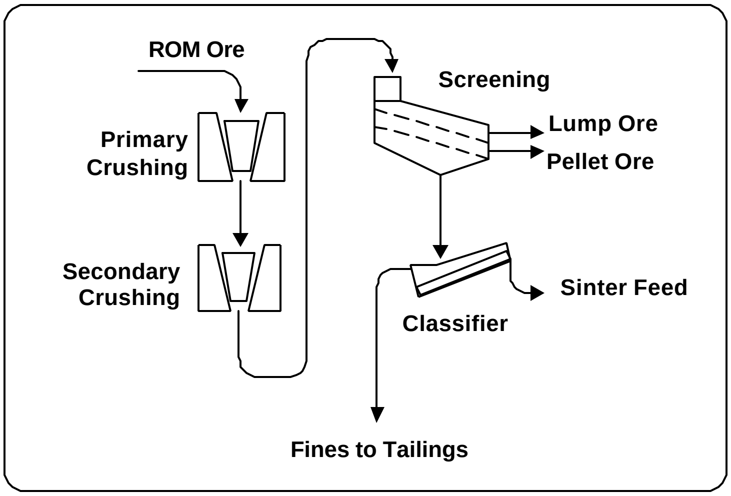

Figure 1 - Typical iron ore processing flowsheet

The depletion of high grade reserves coupled with increasing market pressure for improved product quality has forced iron ore producers to re-examine their process flowsheets and evaluate alternative or supplemental processing routes. A shift in market demand has led to an increased demand for direct reduction grade pellets. The requirement for these high quality pellets demands that the silica content be lowered to levels below 1.0% SiO_2 from feeds containing up to 30% SiO_2. Reverse flotation (silica is floated away from the iron concentrate) has proven to be an economical and effective method for reducing the concentrate silica content to very low levels.

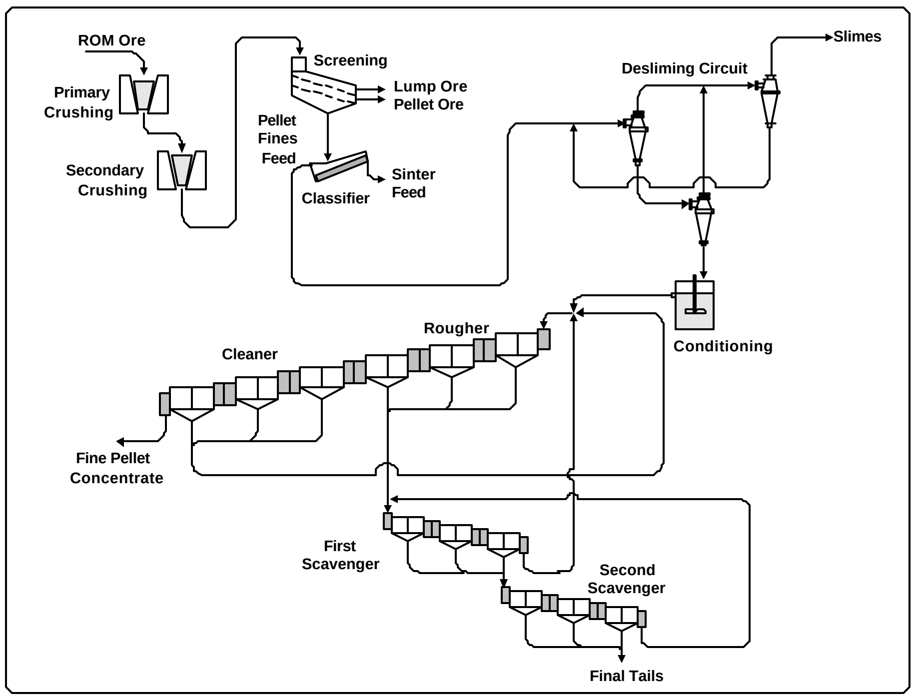

Figure 2 - Flotation circuit using mechanical cells

Figures 2 and 3 show two of the treatment options that were extensively tested. The circuit based on mechanical cells incorporates a rougher and cleaner stage followed by two stages of scavenging to recover fine entrained iron. The ability to wash the froth in the column has resulted in a much simpler circuit as depicted in Figure 3. Comparative results of the testwork are summarised in Table 1.

The results presented in Table 1 are typical of the results achieved by columns in reverse silica flotation applications. Depending on the feed grade, the columns can provide up to 5 % higher iron recovery while producing a concentrate which is lower in silica. The difference in the metallurgical performance can be explained by Figures 4 to 7. Figure 4 shows the distribution of silica by size fraction for the final concentrate produced by the mechanical cells and the column cells. Figure 5 shows the silica assays for each size classification. For size fractions finer than 74 µm, the column and mechanical cells produced concentrates with similar silica assays and distributions. For coarser size fractions however, the column clearly outperformed the mechanical cells.

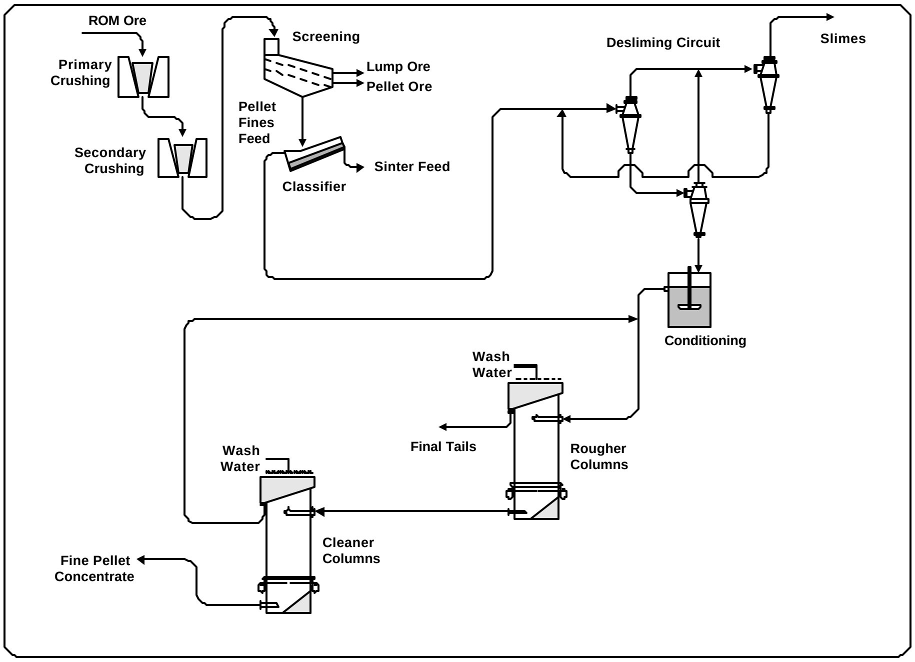

Figure 3 - Flotation circuit using column cells

These results contradict popular beliefs that columns are better suited to fine particle recovery. Provided that the minerals are well liberated, as is the case with the South American iron ores, the coarser size fractions can be successfully floated using columns.

Figures 6 and 7 show an analysis of the final tailings produced by the columns and the mechanical cells. The benefit of using wash water and deep froth beds can be clearly seen from these figures. For sizes coarser than 44 µm, there is virtually no difference in the composition of the tailings. For size fractions finer than 44 µm, however, the benefit of the columns becomes greater as the particle size becomes smaller.

The use of column flotation for removal of silica from iron ores has become the process of choice for South American iron ore producers as well as other iron ore producers world wide. At the time of writing, more than 50 million tonnes per year of direct reduction grade iron ore concentrate are being produced in column cell concentrators.

Table 1 - Comparison of results of column cells versus mechanical cells

		Mechanical Cells	**Column Cells**
Flotation Recovery	Wt. %	74.1	78.2
	% Fe	89.7	93.1
Overall Recovery	Wt %	67.7	71.3
(R.O.M)	% Fe	82.4	86.4
SiO_2 in Concentrate	%	1.7	0.76
Amine Consumption	g/t	38	28
Starch Consumption	g/t	500	500

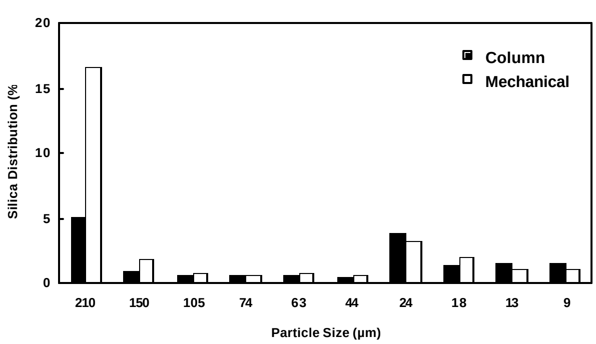

Figure 4 - Silica distribution by size fraction in concentrate

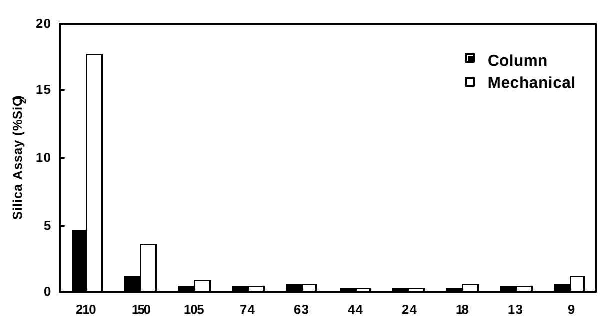

Figure 5 - Silica assays by size fraction in concentrate

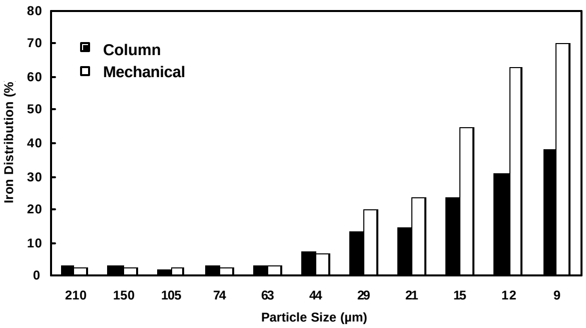

Figure 6 - Iron distribution
by size fraction in tailings

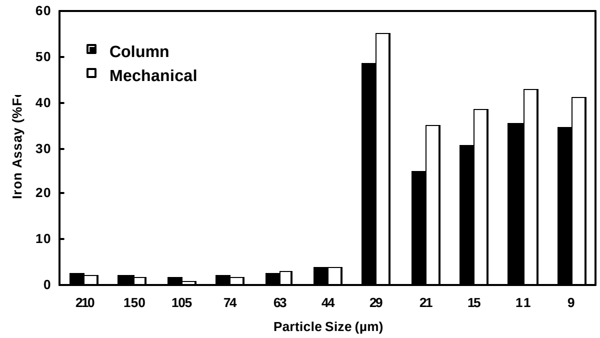

Figure 7 - Iron assays
by size fraction in tailings

Example 2 - Phosphate Flotation

The following example describes a project in which an entire concentrator was converted from mechanical flotation cells to column flotation cells over a period of 2 years as part of a program to reduce plant operating costs.

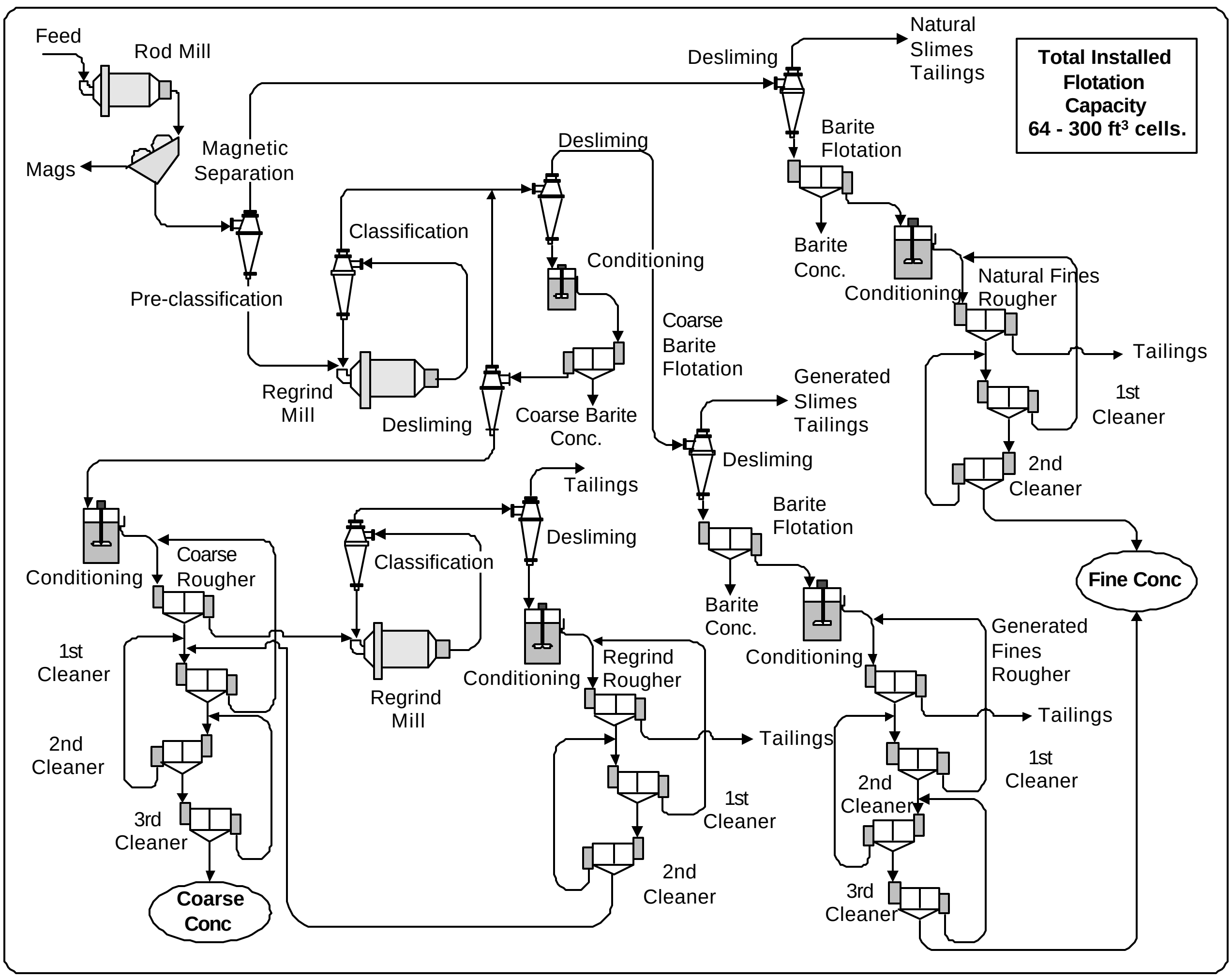

Figure 8 - Phosphate flotation circuit using mechanical cells

The ore is a volcanic phosphate ore containing approximately 20% P_2O_5 primarily as apatite. Principal impurities are barite (9% to 15% $BaSO_4$), hematite (19% to 20% Fe_2O_3), calcite (27% to 28% CaO), alumina and silicates occurring as quartz, micas and clays. The barite is removed in a pre-flotation step using cetyl stearic sulphate as a collector. Due to the radioactivity of the barite concentrate, it has no commercial value. The apatite is recovered by flotation using tall oil as a collector, a froth modifying surfactant for froth control, caustic soda as pH regulator and caustic starch as a depressant. The treatment flowsheet is shown in Figure 8.

The treatment of this type of ore is quite complex. The presence of large quantities of slimes require a staged treatment approach. After an initial coarse grind in a rod mill, the ore is pre-classified into a fine and coarse fractions to separate the naturally occurring fines (natural fines, d80 = 15 µm) from the coarse ore. The coarse fraction is retreated in a closed circuit ball mill and then further subdivided into a fine fraction (generated fines, d80 = 27 µm) and coarse fraction (coarse circuit, d80 = 150 µm) for flotation. Barite is removed prior to coarse apatite flotation. The rougher tailings for the coarse circuit are reground and treated in yet another separate flotation circuit (regrind circuit, d80 = 75 µm). In all, there are five distinct flotation circuits each with a separate desliming section, conditioners and a rougher / cleaner flotation circuit with 2 to 3 stages of cleaning per circuit.

Some of the common problems encountered with the operation of the circuit which led this company to investigate the use of column flotation include:

Continuous Release of Slimes

Even after the ore has been well deslimed there is a tendency to release fresh slimes into the circuit. Many slimes are contained between the plates of the mica. The use of caustic soda in the circuit causes the plates to swell leading to the release of slimes. This process is accelerated by the intense agitation provided by the conditioners and mechanical cell agitators.

High Reagent Consumption

The use of fatty acid collectors often results in problems with control of the froth. The build-up of slimes in the circuit results in high collector consumption which makes the situation worse.

High Re-circulating Loads

The fine nature of the ore requires the use of multiple stages of cleaners to produce acceptable concentrate grades. The cleaner tails are re-circulated to the feed of the previous stage resulting in the development of large re-circulating loads. Control of the re-circulating loads is particularly important in the coarse and regrind circuits. The coarse rougher concentrate is devoid of fines and does not float well in the cleaners. In order to maintain acceptable recoveries in the coarse cleaning circuit the regrind second cleaner concentrate is combined with the coarse rougher concentrate for cleaning. This approach leads to a large re-circulating load through the regrind circuit and ultimately limits the total plant throughput.

A very enthusiastic test program was developed and executed over a seven month period. More than 3,000 tests were conducted using a 600 mm diameter test column equipped with an industrial air sparging system an automatic controls. Every variable that affected the flotation performance was studied and optimized. The results of the test program were very good and a decision was taken to replace the existing mechanical cells with column cells according to the flowsheet shown in Figure 9.

The cell replacement program was completed in two phases. During the first phase, the natural fines circuit and the generated fines circuits were replaced by one column each. For the second phase, the barite flotation circuit and regrind flotation circuits were replaced by one column each and the coarse flotation circuit was replaced by two parallel columns. The total installation project was completed during routine maintenance shutdowns and did not result in any lost production.

The replacement program was extremely successful. The major benefits are summarized below:

Circuit Simplification

Using column flotation it was possible replace the rougher and two to three cleaner stages with a single column producing final concentrate. The total number of flotation cells was reduced from 64 - 300 ft^3 Wemco cells to 6 - 3m x 4.5m rectangular column cells. Re-circulating loads were reduced allowing an increased feed rate to the concentrator. Using the column cells, it not necessary to add fines to the coarse cleaner circuit to achieve froth stability in the cleaners.

Reduced Power Consumption

The elimination of the mechanical flotation cells and associated pumps reduced the total concentrator power consumption by 15%. This figure includes the additional compressor power that was required for the column cells.

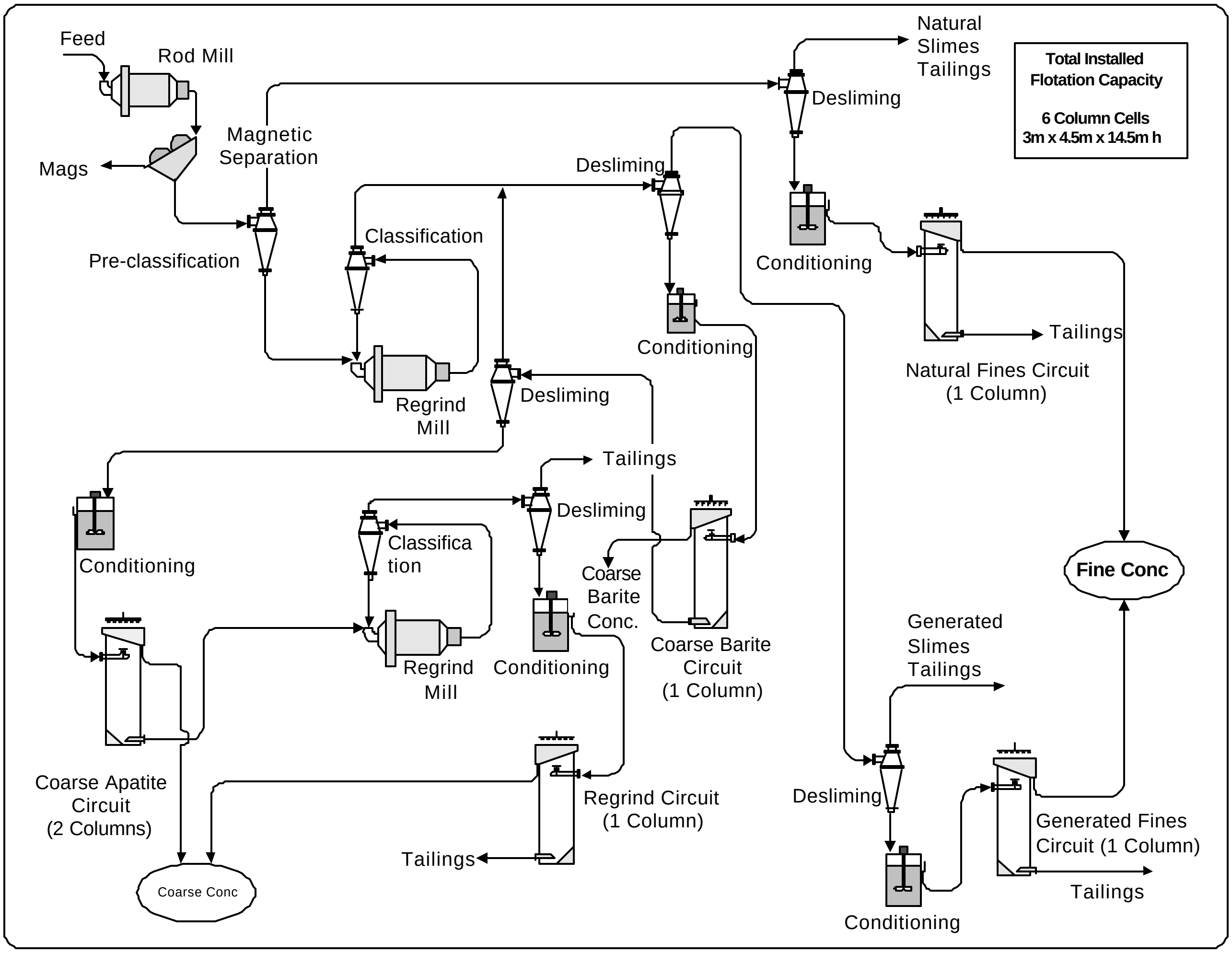

Figure 9 - Phosphate flotation circuit using columns

Improved Metallurgical Performance

The average increase in the concentrate grade was 2% P_2O_5. Overall apatite recovery was 1% to 2% higher.

Reduced Reagent Consumption

The most significant benefit provided by the all column circuit was the reduction in the collector consumption. Improved froth characteristics in the column permitted the use of rice oil as an alternative to the fatty acid (rice oil could not be used with the mechanical cells due to excessive frothing). This change resulted in a decrease in the collector consumption of more than 90%.

Reduced Slimes Generation

The absence of mechanical agitation in the columns has reduced the level of new slimes generation within the flotation circuit and has simplified the operation of the circuit.

SUMMARY AND CONCLUSIONS

Column cells are slowly gaining acceptance for use in roughing applications. With each new successful installation, the degree of confidence in this technology increases. Columns are not suitable for every application and care should be taken when considering this processing option.

The use of column cells as roughers should be considered when the technical and economic benefits can be realized.

Column circuits should not be designed as a replication of mechanical flotation circuits. Key benefits provided by the columns, such as froth washing, should be taken advantage of in the initial design of the circuit.

It is necessary to understand the degree of variability of the ore and the impact that these variations will have on the column performance in order to design sufficient flexibility into the circuit.

The degree of mineral liberation is far more important than the particle when considering columns for the recovery of coarse particles.

REFERENCES

1. Cienski, T., and Coffin, V., "Column Flotation Operation at Mines Gaspe Molybdenum Circuit", 13th Annual CMP Conference, Ottawa, Jan. 20-22 (1981).

2. Coleman, R., and Kilgour, I., "The Installation of a Final Cleaning Column at Ok Tedi", Fourth Mill Operators' Conference, Burnie, Tas 10-14 March (1991).

3. Smithson, E.P., John, C.I.A., Rea, T.H., and Mwenya, W.M., "Improving Concentrate Quality in the Concentrators of Zambia Consolidated Copper Mines Limited Using Column Cells", Column 91 - International Conference on Column Flotation, Sudbury, June 2-6 (1991).

4. Viana, P.R.M., Silva, J.P., Rabelo, P.J.B., Coelho, A.G., and Silva, V.C., "Column Flotation for the Expansion of the Flotation Circuit at Samarco Mineracao, Brazil", Column 91 - International Conference on Column Flotation, Sudbury, June 2-6 (1991).

5. Murdock, D.J., Tucker, R.J., and Jacobi, H.P., "Column Cells VS. Conventional Flotation, A Cost Comparison", Column 91 - International Conference on Column Flotation, Sudbury, June 2-6 (1991).

6. Sandvik, K.L., Nybo, A.S., and Rushfeldt, O., "Reverse Flotation to Low Impurity Levels by Column Flotation", Column 91 - International Conference on Column Flotation, Sudbury, June 2-6 (1991).

7. Levenspiel, O., Chemical Reaction Engineering, Wiley, N.Y., Chap. 9 (1972).

8. Finch, J.A., and Dobby, G.S., Column Flotation, Pergamon Press, Toronto, Chap. 4 (1990)

9. Xu, M., Uribe-Salas, A., Finch, J.A., and Gomez, C.O., "Gas Rate Limitations in Column Flotation", Processing of Complex Ores, (Ed. G.S. Dobby S.R. Rao), Pergamon Press, Toronto (1989).

10. Flint, I.M., Bubble Generation in Flotation Columns, M.A.Sc. Thesis, University of Toronto (1989).

11. Yianatos, J.B., Finch, J.A., and Laplante, A.R., "Apparent Hindered Settling in a Gas-Liquid-Solid Countercurrent Column", International Journal of Mineral Processing., Vol 18, No 3/4, Nov (1986).

12. Ityokumbul, M.T., “A New Modelling Approach to Flotation Column Design”, Minerals Engineering, Vol 5., no. 5/6 (1992)

13. Amelunxen, R.L., “Column Flotation: New Carrying Capacity Considerations for Scale-up”, Expomineria 90', Santiago Chile. May 14-18 (1990).

14. Rasemann, W., “On the Attachment Probability of Bubble/Particle Contacts in Solid/Liquid Suspensions”, International Journal of Mineral Processing, Vol 24, 247-267 (1988).

15. Szatkowski, M., and Freyberger, W.L., “The Effect of Bubble Size Distribution on Selectivity of Iron Ore Flotation”, International Journal of Mineral Processing, Vol 23, 213-227 (1988).

16. Ahmed, N., and Jameson, G.J., “The Effect of Bubbles size on the Rate of Flotation of Fine Particles”, International Journal of Mineral Processing, Vol 14, 195-215 (1985).

17. Bach, H.F., and Pilhofer, T., “Variation of Gas Holdup in Bubble Columns with Physical Properties of Liquids and Operating Parameters of Columns”, German Chemical Engineering, Vol 1, 270-275 (1978).

18. Yianatos, J.B., Espinosa, R.G., Finch, J.A., and Laplante, A.R., “Effect of Column Height on Flotation Performance”, AIME Denver Colorado, Feb. 24-27, (1987).