GRAVITY CONCENTRATION - 1000 YEARS OLD AND STILL IMPROVING

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ABSTRACT

The paper examines the role of gravity concentration in both an historical context and within the modern mineral processing industry. It discusses the principles of the process on both a theoretical and practical level. The importance of ore mineralogy and its effect on the choice of the wide range of equipment available is discussed. The paper concludes with a discussion on the relative merits of gravity concentration to other forms of processing.

INTRODUCTION

It is an unfortunate, albeit popular, misconception amongst otherwise enlightened engineers in the mineral processing industry that gravity concentration was a process developed in the dark ages, perfected in the middle ages and abandoned in the modern ages.

Gravity concentration was developed in the dark ages - long indeed before that. Agricola (1) cites examples of gravity concentration, crude examples admittedly, being practiced over 3000 years ago. That same author devoted a whole book of his masterly treatise to Gravity Concentration. Incidentally to those authors knowledge, that was the last full book ever published solely on that subject - a fact which they are presently rectifying.

Gravity concentration is not dead. Far from it. As recently as 1978 it was reported (2) that the total mineral tonnage treated by this process in the United States was greater than that processed by flotation. Coal represents the bulk of the ore treated by gravity separation in the U.S.A., with iron ore representing a major portion of the balance.

It would however, be erroneous to assume that gravity separation is applicable only to coal and iron ore separation and a few obscure separations where flotation has failed. In general, gravity separation has a lower installed cost per tonne of throughput than flotation for any given job, and usually has a lower installed power requirement. Gravity separation does not use expensive reagents, the cost of which (for flotation) is continually spiralling upward. With the exception of slime disposal (common to flotation), the environmental impact of gravity plant effluent is considerably less
than that for flotation, due to the absence of organic chemicals and their reaction products.

An indication of the broad application of gravity concentration is the variety of minerals presently recovered. A list is given in Table 1; this list is not exhaustive.

TABLE 1

MINERAL REGULARLY RECOVERED
BY GRAVITY CONCENTRATION

<table>
<thead>
<tr>
<th>Coal</th>
<th>Gold</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron Ore</td>
<td>Silver</td>
</tr>
<tr>
<td>Tin</td>
<td>Mineral Sands</td>
</tr>
<tr>
<td>Tantalum/Columbium</td>
<td>Diamonds</td>
</tr>
<tr>
<td>Tungsten</td>
<td>Barite</td>
</tr>
<tr>
<td>Chromite</td>
<td>Fluorspar</td>
</tr>
<tr>
<td>Uranium</td>
<td></td>
</tr>
</tbody>
</table>

Gravity concentration methods separate minerals of different specific gravity by their relative movement in response to gravity and one or more other forces, the latter often being the resistance to motion offered by a viscous fluid, such as water or air.

It is essential for effective separation that a marked density difference exists between the mineral and the gangue. Some idea of the type of separation possible can be gained from the concentration criterion:

\[ \frac{\Delta h - \Delta f}{\Delta l - \Delta f} \]

where \( \Delta h \) = specific gravity of the heavy mineral,
\( \Delta l \) = specific gravity of the light mineral,
\( \Delta f \) = specific gravity of the fluid medium.

In very general terms, when the quotient is greater than 2.5, whether positive or negative, then gravity separation is relatively easy. As the value of the quotient decreases, so the efficiency of separation decreases, and below about 1.25 gravity concentration is not generally commercially feasible.
However, factors such as particle size, particle shape of both the wanted mineral and the unwanted mineral or minerals have to be taken into account; hence use of the concentration criterion alone could lead to some very unpleasant surprises to the unwary design engineer.

Gravity processes depend on two actions singly or combined.

(i) Stratification in a pulsed or moving dense bed usually with a wide size range feed as in jigs.

(ii) Film sizing with a thin flowing liquid film and usually, closely sized solids as in spirals, frames, and tilting concentrators.

Tables, and sluices use a combined action. This leads to two basic types of treatment circuit.

(i) Series circuits, as in sluice dredges, treat comparatively unsized feed in successive stages each producing concentrates, middlings and tailings. Removal or rejection from circuit reduces feed to next stage. One refinement is cut-off sizing of tailings to reject barren oversize (1) and undersize fines (4, 5).

(ii) Parallel circuits treat closely sized feed with multiple units producing concentrates, middlings and tailings in one stage. The efficiency of sizing is an important factor if finished products are required. Generally the two types of circuit are combined. A series circuit of jigs treating unsized feed is followed by a sizing step and a parallel circuit of tables, and film sizing units.

SIZE RANGE

The size range to which gravity separation can be applied is large, some separations are possible as coarse as $500$ millimetres with the practical cut-off regarded as fine as $5$ microns.

Figure 1 shows the range of operation of the more common modern items of equipment. It indicates three broad classifications: coarse, medium and slimes. The top particle size treatable by those units in the broad classification of coarse concentrators is rarely limited by the unit, rather by the top liberation size of the ore. Gravity concentration is the only process available to the mineral processing engineer over such a vast range of particle sizes.
Figure 1: Operating Range-Gravity Concentrating Units

Space precludes a description of the wide range of equipment available; however the interested reader is referred to the literature.

TESTING FOR GRAVITY CONCENTRATION

The first step at the laboratory level, assuming that a fully representative sample has been obtained, should be size fractionation followed by heavy liquid separation of the fractions as described by Mills (6). A prior size reduction step to enhance liberation may, or may not, be necessary. Heavy liquid separations are commonly made in beakers, separatory funnels or in batch-type centrifuges. A complete sequential sink-float analysis of the proposed process feed is usually advisable.

A thorough microscopic study of the various fractions produced in the heavy liquid work is also of vital importance. Probably more can be learned from this than any other technique.

It is possible to determine whether wet gravity separation will be successful in beneficiating an ore, and which gravity unit processes are likely to succeed, purely on the basis of heavy liquid analysis and microscopic examination over the appropriate specific gravity range.
Careful use of Figure No. 1 will outline the most probable items of equipment that can effectively be used for mineral separation.

In fact, the range of possible gravity unit processes can be further narrowed based upon the estimated projected plant throughput. Moncrieff and Lewis (7) have recently compared the feed size range, unit capacity, capital cost and capital cost/unit throughput for various gravity unit processes.

The next stage is to scale-up the data to laboratory scale, which means the production of larger feed samples. Feed preparation must also be considered. This may include grinding to liberation size, desliming, screening to remove unwanted oversize, hydraulic classification or a combination of the above.

Desliming is usually the one feed preparation step necessary for efficient gravity separation in all cases.

Most manufacturers provide small scale versions of their production equipment although results, especially in the fine particle range must be treated with care. Some equipment (especially spirals) should properly be regarded as pilot plant units.

The question of wet gravity separation pilot plant testwork is always controversial, particularly if a continuous pilot plant is envisaged. Because of the high unit capacities of jigs, cones, sluices and spirals, it is difficult to justify a continuous pilot plant unless:

i) It is absolutely essential because of the marginal results so far.

ii) The envisaged plant is large enough that a continuous pilot plant could be built at the mine site, and serve eventually as part of the full scale plant.

iii) The pilot plant equipment needed is mostly already available to a company so that capital costs are low, and the required feed is readily available.

ADVANTAGES OF THE GRAVITY CONCENTRATION ROUTE

Gravity concentration circuits built today are relatively inexpensive, compared with those built previously. Circuits are now much cheaper and simpler, with the advent of such items as spirals, cones, and Mozleys which have cut floor space requirements dramatically.

Indeed such is the relative cheapness of coarse gravity concentration there may be benefit in its consideration
for the rejection of barren waste at a relatively coarse size even in large flotation plants.

How many ores are ground to a size suitable for flotation—without any thought having been given to the actual liberation size of the valuable minerals? Valuable energy, both of the fossiliferous and the human kind, could be saved by a major reduction in the requirement to grind every ton of ore to the fine size required for flotation.

How many times have alternative, and more expensive processes been installed when gravity concentration would not only be cheaper, but would also give better metallurgical performance?

For example, Bath Duncan and Rudolph (8) showed that gravity concentration of gold prior to cyanidation, with that latter process being used only as a scavenger, made a significant improvement in the recovery of very fine gold.

It makes little sense, in the context of economics and the cost of both labour and materials, to ignore any route that can substantially reduce both. So where should one use gravity concentration?

On the evidence of the existing North American coal and iron ore industries, one would automatically look to using gravity separation as a major, if not the major, method of concentration. But what of other areas away from either coal or iron-ore?

Gravity concentration works best for rich ores, for those showing a coarse size of liberation, for placer deposits, for pre-concentration, and for processing in remote areas or where the situation dictates the least expenditure of money. The most difficult to process are lode ores. During the comminution step, a certain amount of fines are always produced, and these fine particles are the hardest to be recovered by gravity processes. The efficiency for concentration of most heavy mineral placer deposits is automatically high since nature has usually removed all of the low-recovery fines and the coarse fraction is barren.

The most obvious examples of high capacity gravity concentration plants in the coarse to intermediate size range are the Australian Mineral sand plants where treatment rates in excess of 1000 t.p.h. are common (9). Elsewhere two examples (10) would be the 37,000 mt/day Climax molybdenum by-product plant in Colorado recovering tungsten and the Palabora plant in South Africa recovering uranium.
At Afton Copper, in Canada, gravity concentration is incorporated at the head of the circuit, recovering native copper at a coarse size, using both jigs and tables.

The chief problem with fine gravity concentration is inherent in the process itself. The decision whether to accept or reject on the basis of specific gravity is typically made on a particle-by-particle basis. This leads to large concentration areas being required. Even with the more sophisticated slime gravity concentrators the lower limit to particle size is still about 10 microns.

Slime plants have been used to scavenge metal oxides from the tailings of large sulphide flotation plants. The recovery of tin by Buckman concentrators from Cominco's Sullivan concentrator (11), and by Bartles-Mozley separators and Holman slime tables at Kidd Creek Mines plant (12) are well documented.

A notable example of the competitiveness of slime gravity concentration is in the recovery of tin ores. Even though a great deal of research has been carried out to develop efficient tin flotation flowsheets very few have proved satisfactory. Probably the only truly satisfactory route incorporates roughing, with several successive cleaning stages of thoroughly deslimed fine ores. Nevertheless, the cost of such a route is high.

Apart from the cost of reagents, power plays a major part in these high costs. The need for adequate desliming for flotation is met by a triple-stage cyclone desliming operation. Desliming is equally beneficial to gravity concentration, but there are few, if any instances in which such elaborate desliming is carried out before the traditional processes.

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