OVERVIEW OF DIAMOND RECOVERY TECHNIQUES

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DIAMONDS – SOURCE TO USE COLLOQUIUM

SYNOPSIS

The topic is a very broad one. It starts at the mine tip and ends at the sorthouse, just prior to classification and parcelling of diamonds.

The paper introduces the challenges facing an Extractive Metallurgist, or Plant Designer, as a result of the widely ranging diamond occurrences and associated minerals.

It reviews the unit processes available, and those currently favoured, for extracting diamond from the ore.

INTRODUCTION

While diamond recovery methods have become more sophisticated over the years – to continually improve recovery, operating efficiencies and maximise value – they still follow the golden rules of mineral dressing, "viz. careful liberation" of the mineral in a staged manner if necessary, followed by "extraction and concentration thereof".

Prior to liberation, the run of mine ore is drawn into the process via what is a critical, and often found to be the most problematic step of the operation, "the front-end".

UNDERSTANDING THE ORE AND ITS CHANGES OVER TIME
(or the Geologist's explanation thereof!)

Of all the minerals an extractive metallurgist encounters, diamond bearing ores are arguably the most challenging. Not only are the sources hugely variable from one field to another, but often a particular operation requires a design to treat changing ore properties over the course of its life.

Alluvial gravels display varying physically properties, from simple free flowing alluvial gravels well washed by river action, to conglomerates, and to sticky ores with different levels of clay or laterite.

The occurrences could be dry, allowing up-front up-grading by in-field screening or magnetics removal, to wet or frozen material.

Surface Kimberlites and Lamproites are generally "weathered and claggy" converting to more competent "blue ground" as the mining depth progresses, requiring more demanding liberation techniques. Similar challenges are offered by dykes, sills and fissures.

Marine gravels display unique features including prevalence of different types of shell, silt, clay, in association with extraneous material e.g. sea weed, jelly fish.

Consistent with most valuable minerals, tailings are another source of ore, but unlike homogeneous slimes dam, often mined for gold recovery, the coarse dumps constitute the ore body, with varying occurrence of tramp and contaminant.

Not only do the wide range of ore types call for careful unit process selection for the front-end handling and subsequent liberation phases, but the range of associated mineral demand extensive separation and recovery techniques.

LIBERATION

Scrubbing, crushing and screening constitute the commonly used liberation techniques, but the specific recipe, viz., the extent, the phasing and the type of process action, in each case, is dictated by the ore type and diamond occurrence.

There is no standard. It, therefore, requires a good theoretical knowledge of ore dressing techniques coupled with experience, which is why extractive metallurgy is sometimes considered a "black art".

Scrubbing

Horizontal tubular rotating scrubbers are the norm, although there is place for a higher operating risk log washers, which have greater specific energy input. Scrubbing is required to:

- De-agglomerate the ore and to expose locked diamonds.
- Break down clays that may hinder down stream processes.
- Break down compressed ore cakes created by High Pressure Roll Crushing.

Variables that need consideration include:

- Scrubber solids residence time.
- Scrubber solids to water ratio.
- Medium charge requirements.
- Critical speed.

Jet Pumping

Jet pumping is a convenient method of transporting sensitive material. At the same time a degree of attritioning, or scrubbing takes place.

Some successful jet pumping applications include:

- Dump reclamation and where a limited amount of scrubbing is required, the two unit processes are conducted in one operation.
- Moving material from wet bins on board a ship or floating treatment plant, where there are space limitations.
- Dredging.

Characteristics include:

- Pumping efficiencies are low.
- Water usage is high, requiring careful re-cycle consideration.
- Capital costs are low, in comparison with conventional conveying and scrubbing but at the expense of operating costs.
- Pumping heads are limited, sometimes requiring a booster pump in the circuit.

- Availability – The particle top size must be carefully monitored to prevent blockages (while the system comfortably withdraws material from a source of high solids concentration, the ingress of tramp or large particles severely impacts on availability. In respect of the latter, further work on materials of construction, particularly post the pump is necessary to reduce stoppages due to wear).

While there are particular attractions to incorporating jet pumping in a flowsheet, careful trade-off assessment should be conducted, as is the case with any unit process consideration.

Crushing

Various crushing techniques are used in the diamond industry. As is common with all mineral treatment plants, crushing plays a role not only in reducing the ore to a size suitable for down-stream processing, but more importantly in liberation of the sought after mineral.

A range of crushers are employed, depending on ore type and application, namely:

- Dry and wet jaw crushing. The latter is unique to the industry and useful when treating weathered ores that will ultimately become competent. Generally used in primary applications.
- Toothed double roll crushers, best suited for claggy ore.
- Wet and dry cone crushing, in secondary applications;
- Various forms of inter-particle crushing, with High Pressure Roll Crushing playing a dominant role when treating competent kimberlites.
- Inter-particle impact crushing is also used where differential crushing can be employed to advantage.
- The nutating mill. While not strictly fulfilling a crusher duty, this has found application in the mass reduction of DMS concentrates

PRIMARY CONCENTRATION

By far the most commonly used method of primary concentration is separation by gravity.

Equipment employed includes Dense Medium Separation (DMS) Cyclones, Pans and Jigs, all of which rely on differences in specific gravity to separate diamond (density 3,52) from the gangue. While the latter ranges in density, the bulk of the host rock is less dense, with densities lower than 3,0.

DMS Cyclones

The universally recognised measure of efficiency of separation is a partition curve. This describes the probability of a particle of certain density reporting to the dense or sink fraction.

Clearly the process engineer will design the plant so that a particle of 3,4 or denser has a 100% chance of reporting to sinks, but at the same time, one attempts to minimise the quantity of sinks. The more near gravity mineral there is, the more important it is to use equipment with a sharper partition curve. Typical partition curves are shown in Table 1.

What is evident is that for a given separating vessel, the coarser particles have a greater propensity to sink, displaying a lower d50, and visa versa. Also, the surface tension effect results in greater drag being applied to the smaller particles, so that the finer particle curve is flatter, displaying a longer tail.

The differing cut points for different particle sizes has led to the call for separate circuits to process the "fine" and "coarse" particle sizes.

This is a feature of any mineral extraction process – the narrower the size range, the more efficient the process. The down side though, is each circuit needs a capacity up-rate and/or requires adequate surge capacity ahead of it. Still, plant utilisation is generally sacrificed, for widely ranging feed stock size distributions. Careful assessment accompanied by dynamic simulation is required when reviewing the flowsheet circuit.

Considerations in the design of cyclone plants include:

- Understanding the top and bottom particle sizes for maximum "dollar" extraction value. Chasing the fine diamonds can be at the expense of throughput, which point should be part of the project's financial evaluation.

- Particle size range – the efficiency of separation is most strongly influenced by the range treated in a cyclone, particularly in respect of maximising fine diamond recovery and minimising yield.

- Cyclone pressure – the higher the pressure, the greater the centrifugal force generated. These forces are needed to overcome the surface tension drag, particularly in respect of the small particles (the plus 10mm particles could just as efficiently be separated in a static bath). While some operators prefer running at lower than DSM feed pressure recommendations, we advocate no less than a pressure equivalent to 14 cyclone diameters for fine diamond separators.

- Cyclone size and number – assuming it is practical to limit the size range treated, the criticality of using small cyclones for the fine particle separation diminishes. Given the importance of constant and even flow to the individual cyclones, it becomes a trade-off between a larger single cyclone, and a number of smaller cyclones whose efficiency is dependant on the longer term performance of a distributor!

- Rheology – a critical factor which is influenced by medium selection and affected by medium contamination and the design of the recovery circuit. A number of papers have been presented at the Samancor Dense Medium Conferences on this topic. Suffice to say, a balance between viscosity and medium stability is required which is, in turn, reflected in the cyclone differential.

Pans

There is definitely a place for pans in the industry. They have the following advantages:

- A lower power consumption.
- Generally lower water consumption, but this depends on the ultra fines content which must be continuously removed with water.
- Generally a lower operating cost, depending on how they are built.

However,

- They produce a higher concentrate yield. Astute operators remove 10% or more to compensate for lower efficiencies (in this instance they often require a DMS Cyclone circuit to "concentrate the concentrate").

- They pose an enormous security risk.

- They have unacceptably low recoveries, measured on a "life of mine" basis. This is governed as much by the variables inherent to the pan operation, and the necessary human control thereof. While spot efficiencies up to 95% recovery are common in a single stage, long term recoveries quoted can be as low as 70%. In an effort to replace the reliance on the human element for satisfactory efficiency, De Beers identified in excess of 40 variables, many of which would need to be monitored and controlled continuously during operation.

Common key operating criteria include:

- Concentrate tapping – frequency and duration.
- Puddle condition – while viscosity is the relevant criteria, density is more readily measured and is, therefore, used in the field.
- Pan teeth - condition and depth.
- Weir overflow height.
- Rotational speed of the rakes.

Jigs

Jigs display similar characteristics to pans in terms of recovery and concentration efficiency, and relative capital and operating costs. They should, and generally are, used as no more than pre-concentrators, or as a specialist device.

In terms of the latter, they are successfully used for coarse removal of shell in marine applications. In recent times, Gekko are beginning to establish their mark on the industry. The jig operates under an internal pressure of nearly 1 bar which, claim the manufacturers, results improved efficiencies of separation over conventional jigs. At time of writing, however, partition curves based on the two or three world wide applications are, as yet not forthcoming.

RECOVERY

One may associate the recovery plant with the name "Aquarium" penned by De Beers which arose out of the marriage of two concepts:

- CARP – Completely Automated Recovery Plant.
- FISH – Fully Integrated Sorthouse

This concept however represents the upper end of the technology scale. At the other end is the digger with a table, eye glass and tweezer.

Ultimate reduction of the diamond bearing concentrate takes place in the recovery plant where unit processes other than gravity are employed. The recovery plant feed stock is generally a DMS cyclone concentrate, which depending on the ore body and its heavy mineral content comprises less than 1% of the ROM. This, however, can vary up to 5% (generally when accompanied by the presence of illmenite). In some alluvial operations the yield is less than 0,1%.

Magnetic Separation

The process route is governed by the minerals present. Generally, the higher concentrate yielding ores contain magnetic or para-magnetic minerals that are amenable to the use of the following magnetic separation processes as a bulk reduction step.

- Low intensity drums used in conjunction with rare Earth Drum Separators (REDS).
- Wet and dry high intensity roll separators.

X-Ray Treatment

X-Ray recovery relies on a unique property of diamond in that it fluoresces (emits light) when bombarded by X-Rays. Whilst the various equipment manufacturers all employ this means of identification they use different techniques to present and separate the fluorescent particles from the waste.

Wet and dry methods can be employed each having their benefits. The costs associated with drying large amounts of DMS concentrate can be significant. Dry processes also generate a lot of heat and dust, both of which need to be managed. Drying however improves feed rate control and permits the use of a dry magnetic pre-concentration stage such as Reds or Permroll ahead of X-Ray recovery reducing capital costs.

In wet X-Ray sorting it is only the concentrate, which needs to be dried, and depending on the size range, the up-grade could be 100 times.

De Beers uses in-house developed X-Ray technology, which is generally not available to outside operations. This consists of a range of dry, broad belt up to 32 channel or freefall (CDX) machines. After detection the diamonds are ejected from the gravel stream using short supersonic blasts of compressed air or electromechanical gates.

The larger independent operators such as BHP (Ekati) and Diavik (Aber/Kennecot) have selected a range of wet and dry machines from Ultrasort, the high capacity (DPGD) wet basket machines have proven to be efficient and robust in the required duty.

The majority of the smaller operations rely on the Flowsort wet chute X-Ray machines to recover their diamonds. These simple, compact units are easily installed and maintained. More than 200 are operating around the world.

No matter how selective the X-Ray machine optical / ejection systems are, there are always a number of non-diamond particles extracted with each ejection. This often results in the need for a re-concentration stage after primary and secondary recovery. This re-concentration stage is important as it reduces the amount of concentrate that needs further up-grading.

Single particle sorters (SPS) are becoming the norm for the latter in larger operations, and it is a matter of time before this becomes an industry standard for smaller operators. The biggest obstacle being cost and reliability.

X-Ray machines are set up and their efficiency is measured using luminescent tracers with different intensities. However, the only means of establishing the true efficiency is to audit the machines using a different recovery technique such as permrolls or grease belts.

Whilst X-Ray recovery is second only to grease with its selectivity, it also has problems, which need to be addressed, accessory minerals such as calite and zircon cause problems with yield. The use of optical filters can often address these issues.

One area where even the use of sophisticated electronics is unsuccessful is in the recovery of slow rise time, (typically type IIB) diamonds which are often very good quality stones which are not "seen" by the X-Ray machines. The only practical way of recovering these and other stones lost by the X-Ray machines is the use of grease, or DB collector to be precise.

DB collector is a blend of petroleum jelly and bees wax and is mixed in different proportions to compensate for temperature.

Grease

The use of grease belts and tables to recover diamonds has fallen out of favour mostly due to security concerns.

Housekeeping and maintenance issues have also played a roll. The majority of diggers and smaller operators rely on the selectivity of grease for their diamond recovery, as the cost of installing and maintaining X-Ray machines is beyond their means.

The problems associated with grease belts and tables can be managed through careful monitoring and engineering during the design phase.

Alternate Techniques

There are a number of techniques being developed to improve recovery efficiency all of which try to exploit one or other property of diamond including:

Laser excitation (Raman effect)
Optical sorting
Colour sorting
Shape recognition
Thermal conductivity
Thermal imaging

Despite all the technology used to identify and recover diamonds, the final step in the process cannot be replaced by a machine.

Identification, defalsification, grading and valuation is still largely performed manually using the human eye as the ultimate test.

Sorthouse

The final stage of the diamond recovery process takes place under secure and controlled conditions in the sorthouse.

In some high volume-low value operations where there are a large proportion of fine diamonds bulk treatment of the concentrates is required to limit the amount of additional handsorting needed.

- At MIBA where fine diamond production is in the region of 30 000 cts/day lead sulphamate is used to separate diamond from waste.

- At Argyle where more than 100 000 cts of diamond are produced daily (far too much to be hand sorted) the entire production is subjected to caustic fusion which not only dissolves the waste material but also improves the diamonds appearance by removing oxide coatings.

In large scale low volume-high value operations "hands off" principles are applied, limiting human involvement by using laser based single particle sorting equipment.

Under other conditions, however, handsorting remains the predominant method of removing the diamonds from waste. The use of single handed glove-boxes together with camera surveillance have improved security of the product.

There is a growing tendency to centralise sorthouse operations, allowing multiple sources to be treated at a single location. This has led to the development of novel storage and transport devices such as the Fuseatron canning machine and canlock/docklock containers. Sophisticated counting packing and weighting equipment is being developed to provide an audit trail for the diamonds produced by the mine before being exported to the central sorthouse facility.

CONCLUSION

With the first discovery of diamonds in India dating back more than 2000 years to the more recent Canadian discoveries, many methods have been employed in their recovery. Some techniques have fallen from use but re-appear in different guises from time to time. Who knows, maybe the next revival could be grease!

One thing is certain, that given the diversity of operations, in the industry, cost considerations, simplicity and recovery efficiency will be the determining factors in selecting the appropriate technology and treatment routes.

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