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What is your PGM concentrate worth?

L.A. CRAMER

There are a couple of dozen junior platinum mining companies coming into existence in Southern African and most intend to mine, concentrate the PGM's in a flotation product and sell the concentrate to one of the major producers in South Africa. The price they will receive for their product and hence the return they achieve for their investment will depend upon the large number of factors that influence the market for such a product. Unfortunately the number of buyers is severely limited as it is dominated by the two major local producers, Impala Platinum and Anglo Platinum. Furthermore the current smelting technology has limited capacity for UG2 concentrates and high nickel concentrates will quickly fill any available base metal refining capacity. Few if any overseas buyers can compete for the bulky flotation concentrate produced.

This paper will explore those factors such as metal recoveries, metal prices, operating costs, capacity constraints, deleterious elements, transport issues, metal premiums and discounts that are in play, types of flotation concentrates, processing capital costs, PGM grades, etc and their impact upon what smelters and refiners might be prepared to pay for such PGM concentrates.

Ultimately simple graphs and equations can be developed for probably payment terms for such concentrates. Those who negotiate well will move to the higher return section of the envelope and those who use the concentrator facilities to produce the most saleable combination of flotation concentrates will enhance their returns. A deep and firm understanding of the issues surrounding this market is necessary in order to negotiate the best possible price for the seller.

Introduction

Some twenty-six new platinum projects have been announced such that there will be a couple of dozen junior platinum mining companies coming into existence in Southern African over the next decade and most intend to mine, concentrate the PGMs in a flotation product and sell the concentrate to a smelter and refiner of PGMs. The price they will receive for their concentrate and hence the return they achieve for their investment will obviously depend upon the large number of factors that influence the market for such a product. Metal prices, smelting and refining opex and capex costs, processing pipelines, technical efficiencies and capacities are but some of the factors. The number of potential buyers is severely limited as the local market is dominated by the two world's major platinum producers, Impala Platinum and Anglo Platinum. Furthermore the conventional smelting technology has limited capacity for the chromite in UG2 concentrates and high nickel concentrates from Merensky or the Platreef will quickly fill any locally available base metal refining capacity. Few if any overseas buyers can offer better terms for the metal value contained and the significant transport costs preclude overseas sales of the bulky flotation concentrate produced. Furthermore, the South African government would prefer to have mineral resources beneficiated to a high degree in South Africa.

This paper will explore those factors such as metal recoveries, metal prices, operating costs, capacity constraints, deleterious elements, transport issues, metal premiums and discounts that are in play, types of flotation concentrates, processing capital costs, PGM grades, etc. and their impact upon what smelters and refiners might be prepared to pay for such PGM concentrates.

The processing structure of the Southern African platinum industry

The South Africa Bushveld Complex is the largest known source of platinum group metals (PGMs) in the world and in conjunction with the Great Dyke in Zimbabwe these deposits contain somewhere near 90% of the known PGM reserves. Russian production and reserves are significant but much more heavily weighted toward nickel and palladium for their revenue than the Southern African deposits, which are platinum rich. The Canadian producers are primarily nickel producers with PGMs as a by-product.

The Southern African PGM industry is dominated by Anglo Platinum, Impala Platinum and Lonplats, in that order. According to the 2008 Johnson Matthey Review, Anglo Platinum produced 37.7% of the world supply of Pt followed by Impala at 16.6%, Lonplats at 12.8%, Aquarius Platinum at 3.7% and Northam Platinum at 2.9%. In total Southern Africa supplied 76.9% of the world's platinum in 2007.

The local industry is comprised of a large number of underground mines and several surface or opencast mines and an almost equally large number of concentrators (Anglo Platinum has more than 10). The flotation concentrates from these operations flow to only six smelting sites consisting of conventional six-in-line submerged arc furnaces, with only four sites having converters and only two have acid plants for sulphur recovery. Anglo Platinum has furnaces at three sites, Rustenburg, Polokwane and Swartklip, with converters and an acid plant at Rustenburg only. Impala has furnaces, converting and acid plant operations at the same base near Rustenburg. Lonplats has centralized furnace and converting operations at Mooinooi

(east of Rustenburg) and Northam has furnace and converting operations on mine near Thabazimbi, but neither of these sites have acid plants for SO^2 gas capture. Base metal refining capacity exists for all four major producers at Rustenburg for Anglo Platinum and Impala, at Mooinooi for Lonplats and near Thabazimbi for Northam. However the Lonplats and Northam base metal refining operations recovery copper only as cathode the nickel/cobalt is sold as a combined nickel sulphate to other refiners (Bindura, Impala and Anglo Platinum). Thus nickel refining capacity is primarily limited to that available at Anglo Platinum and Impala; a small amount of nickel refining capacity is available at the Zimbabwean nickel producers, Bindura Nickel and Empress.

Internationally the market for nickel and PGM concentrates is dominated by the Canadian nickel producers, CVRD-INCO and Xstrata (Falconbridge); however, the Chinese demand for commodities is bringing Chinese companies into competition for nickel-bearing concentrates/mattes in some instances. CVRD-INCO processes concentrates and mattes in Canada whereas high grade PGM concentrates are processed in England. Xstrata/Falconbridge processes concentrates in Canada and mattes/PGMs in Norway.

Junior platinum mining companies are in various stages of development throughout South Africa; most of these companies intend to mine and concentrate the PGMs into a saleable flotation concentrate, although there are several studies ongoing on further upgrading their product as a furnace matte, a converter matte or various other intermediate and saleable products. Table I lists the more significant projects at this time.

Faced with limited capacity for concentrate smelting and base metal refining within the local platinum industry, many junior mining companies are considering adding value to their flotation concentrates through further investment in process capacity, often in conjunction with other smaller companies who face similar constraints or together with one of the major platinum companies. However, the capital commitment for mining and concentrating is significant such that most projects find it difficult to fund the added investment into smelting, base metal refining and PGM refining facilities. Obviously the shortage of smelting and base metal refining capacity is being considered by all of the major platinum producers as well, and various studies are underway by Lonmin, Impala at least; Anglo Platinum is also expanding its base metal refinery to handle the extra nickel from its expanded Platreef project.

Types of flotation concentrates

The Bushveld Complex in South Africa broadly speaking consists of three basic PGM containing orebodies; these are the Merensky Reef, the UG2 Reef and the Platreef. Initially the Merensky Reef was the major source of PGMs but as these deposits at or near to surface have become depleted the lower grade UG2 Reef has been increasingly mined. The Platreef deposits are located in two breakaway portions of the Bushveld Complex: one in the northern area near Mokopane and the second in the south eastern area near Groblersdal. Some of the Plat Reef deposits are more suitable to open pit or surface mining and tend to be lower in PGM values but higher in base metal values; these orebodies have been the last of the three to be exploited. Expectedly these ores when concentrated produce quite different flotation concentrates that respond to further processing differently.

Merensky concentrates will generally have a higher Pt/Pd ratio and contain significant amounts of nickel and copper; UG2 concentrates contain a larger percentage of the PGMs as Rh and are lower in nickel and copper. Platreef concentrates can be similar to Merensky concentrates from some orebodies but can also be much lower in PGM's and significantly higher in nickel than Merensky concentrates; those from the southeastern area are primarily nickel orebody with some PGM credits. UG2 concentrates often contain a few percentage points of Cr_2O_3 as a spinel; this does not breakdown and melt in the conventional submerged arc electric smelting furnaces, leading to more viscous slags, higher operating temperatures and larger PGM losses; this is exacerbated by the low level of matte forming materials (base metals and sulphur) needed to collect the PGMs. Consequently this type of concentrate is generally smelted by blending it with Plat Reef or Merensky concentrates and limits of around 1% in terms of Cr_2O_3 content in the smelter feed are observed. The Eastern and Western Limb of the Bushveld complex affects the PGM distribution as well as the ratio of PGMs to base metals in the concentrates; the Eastern Limb tends to have more Pd and base metals than does the Western Limb.

Table I
Junior platinum mining projects

Company	Operation	Product	Comment
Anooraq Boikgahtsho PMJV	Ga-Pasha and	Concentrates Anglo Platinum's Polokwane furnace	Option to buy into
Barrick Gold	Sedibelo	Concentrates	Smelter study being done
East Plats	Kennedy's Vale/Spitzkop	Concentrates	Smelter study being done
Ivanhoe Platinum	Reitfontein	Concentrates	
Jubilee platinum	Tjate	Concentrates	
Nkwe Platinum	DeWildt	Concentrates	
Platmin	Pilanesburg	Concentrates	Smelter study in progress
PTM	Western Bushveld JV	Concentrates	
Platinum Australia	Smokey Hills	Concentrates	
Pan Palladium	Grass Valley and Aurora	Concentrates	
Ridge	Blue Ridge and Sheba's Ridge	Concentrates	Smelter study done for Sheba's Ridge
Xstrata	Elandsfontein	Concentrates	
Wesizwe	Ledig	Concentrates	Smelter study in progress

Although the range of assays for the various types of concentrates is large, Table II gives some typical values for each type. These will form the basis of comparisons in the rest of this paper.

The conventional processing route for PGM concentrates

Flotation concentrates from PGM mining operations are treated through several steps to extract and separate the valuable metals. A typical flowsheet is given in Figure 1 and consists of the main processes of smelting, base metal refining and precious metal refining. Smelting contains the sub-processes of concentrate drying to remove moisture, electric smelting to remove as slags the silicates, aluminates, magnesia and much of the iron, converting of the furnace matte to reduce sulphur content and essentially remove iron, gas cleaning and SO_2 capture as sulphuric acid and matte granulation or crushing. The second process of base metal refining consists of the sub-processes of milling, sulphate leaching, impurity removal (Se, Pb, Zn), Cu electrowinning, cobalt removal and recovery, Ni electrowinning or hydrogen reduction and sulphur disposal. Lastly the residue from the base metal refining process is transferred to the third process of PGM separation and refining. The sub-processes here are leaching, solvent extraction, ion exchange, precipitation, distillation, effluent treatment and metal preparation. In base and precious metal refining forming, packaging, storage, marketing and shipment of the purified metals absorbs resources. The high level of security in the precious metals refinery is critical and adds further costs to the metal recovery.

Table II
Typical PGM flotation concentrates

Assay	Merensky	UG2	Platreef	Hi-Ni Platreef
PGM – 4E	200	200	120	30
Pt - % of 4E	63.5	56.7	45.1	24.0
Pd	28.1	29.4	45.7	69.3
Rh	4.4	13.0	3.2	1.3
Au	4.0	0.9	6.0	5.4
Ir	0.6	1.6	1.0	-
Ru	6.8	9.6	3.5	-
Ni %	6.0	1.4	4.9	6.0
Cu	3.4	0.7	2.5	4.0
Co	0.15	0.05	0.2	0.07
Cr_2O_3	0.6	3.0	0.3	0.1
Sulphur	15–20	4–6	10–15	15–20
USD value/t**	14 009	16 526	7 397	2 923

** Based on Pt – $2000/oz, Pd – $450/oz, Rh – $9000/oz, Au – $900/oz, Ir - $450/oz, Ru – $450/oz, Ni – $12/lb, Cu – $3.80/lb, Co – $50/lb

There are of course process variations in the above typical PGM process flowsheet that have an impact upon capital and operating costs as well as extraction efficiencies and product purities. Rotary kilns, multiple hearth dryers, spray driers and flash driers have all been used in the past; currently the bulk of the industry uses flash driers. Circular as well as rectangular submerged arc furnaces have been used to produce furnace mattes and electrical capacities ranging from a few MVA to as much as 65 MVA. Larger furnaces are generally much more energy efficient and as such the scale of operations has an impact upon smelting costs. Converting has traditionally been accomplished in Pierce-Smith converters but recently the Ausmelt process has been used to convert the furnace mattes. These methods need different methods of furnace matte handling (hot and molten or cold and crushed) affecting capital and operating costs. In some operations slag milling is practised to recovery as much of the PGM value as possible and recycle slag milling flotation concentrates to the smelter and in others slag cleaning furnaces are required to improve overall recoveries; these complexities add to capital and operating costs.

In conclusion, considerable monetary resource (capital and operating costs) as well as considerable technical skill is dedicated to the process stream that converts the metal value in a flotation concentrate to saleable metals. Recovering the valuable metals (nickel, copper, cobalt, platinum, palladium, rhodium, gold, iridium, ruthenium, osmium) and separately them from one another is a complicated and time - consuming technical process. In some instances high grade residues or intermediate products are shipped overseas to specialist refiners for treatment, which adds to the operating cost and to the process inventory of metals.

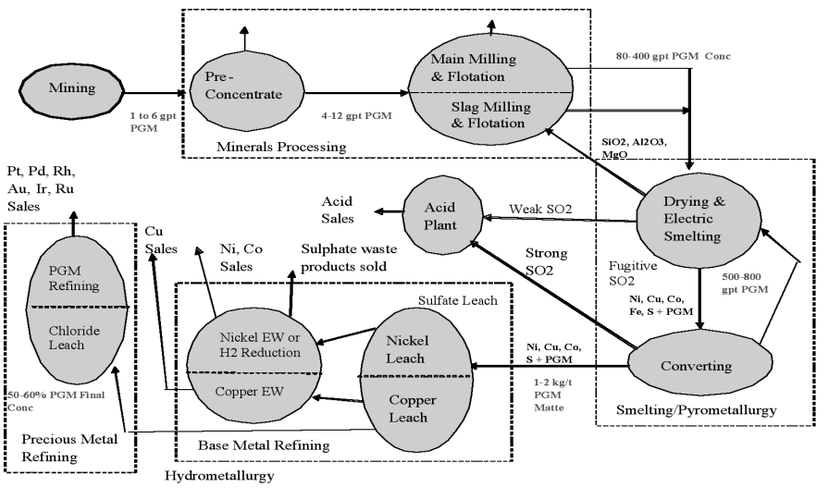

Figure 1. PGM Typical flowsheet

The major economic factors in concentrate treatment

The economics of processing flotation concentrates containing PGMs is determined by several principle factors: these are operating costs for the metallurgical processes, the capital costs of establishing the facilities for these processes, the metallurgical process efficiencies of first-pass and ultimate recoveries, and the costs of financing the significant inventory of such highly valued metals. Less important factor but those that may influence what a particular refiner is prepared to pay for a flotation concentrate, are such issues as the chromite content of the concentrate, the form and purity of the final refined base metals from their specific facility, sales of waste products such as sulphuric acid and base metal refinery sulphates, and the level of discounts offered to final PGM purchasers (motor car manufacturers, etc.). For example, cobalt sulphate usually carries a market premium as does high purity electrowon nickel and copper; low spec copper can attract as much as a 20% discount from the LME price whereas electroplating grades of nickel can attract as much as a 10% premium on the nickel price. Discounts on PGM free market prices have been given from time to time by the refiner to the major purchaser and historically have been as high as several percentage points. Chromite (Cr_2O_3) is seen as a particularly deleterious compound in the smelting stages for the reasons given above and depending upon the particular refiners' blend of concentrates for smelting at a particular, site may attract penalties of around 1% of the metal value. Furthermore each specific refiner may vary his price offered depending upon the available capacity he has installed; where possible each smelter and refiner would like to operate at full capacity so as to lower his average unit costs. These operations have a high fixed cost component within the normal range of operations and my estimates are smelting (50% fixed costs), base metal refining (about 65%) and the precious metals refining operations (about 85%).

Operating costs – OPEX

Operating costs for the conventional processing facilities (smelting, base metal refining and PGM refining) can be broadly viewed as being driven by different factors in each of the three facilities. In the case of smelting the major cost driver is the tonnage of concentrate to be smelted and although not 100% accurate it is reasonable and convenient to use concentrate tonnage as the cost driver. Drying, furnace and slag milling/flotation costs within the range of normal operation levels for any single smelter are very tonnage related whereas converting and acid plant costs are more driven by base metal contents and by sulphur content of the concentrate. Differences in the costs between Merensky and UG2 concentrates due to the converting and acid plant cost drivers is assumed to be small enough to ignore; however, in the case of the hi-nickel low-PGM Plat reef concentrates it must be considered that the assumed operating costs (if driven solely by concentrate tonnage) are probably lower than they would be in reality as the high matte falls and high sulphur values will lead to greater converting and acid plant costs than for Merensky or UG2 concentrates. Smelting average costs in the industry vary between R800 and R1 400/t of concentrate smelted; for the purposes of this exercise I have assumed a cost of R1 200/ton of dry concentrates.

Base metal refining costs are more complex and the cost drivers can be viewed as being matte tonnages or base metal tonnages. Because the smelting process produces mattes of a very similar nature (45–46% Ni, 26–27% Cu, 1% Co, 1–3% Fe and 22–24% S) for the base metal refining of these mattes both approaches lead to similar results. While there are differences between the two major base metal refineries in South Africa which affect the site, specific costs, both are largely driven by the cost of neutralizing the acid formed and disposing of sulphur (as ammonium sulphate or as sodium sulfate), the electrical costs of Cu and/or Ni electrowinning (or hydrogen generation for hydrogen reduction of nickel), cutting and packing of the final products; all of these are largely tonnage driven. Base metal refining costs in the industry vary between R10 000 and R14 000/t of matte; for the purposes of this exercise an average cost of R13 000/ton of dry matte processed is assumed.

Precious metal refining costs are largely fixed in nature as mentioned above; consumables such as power, chemicals, resins, etc. are a small part of the operating costs. Items that are more fixed in nature such as labour, security, administration, effluent treatment, maintenance costs, etc. are hardly affected by the volume of PGMs being processed. Still to the extent that the costs have a driver the volume capacity of 4E PGMs processed is a convenient industry measure and within a small range of volume variability will accurately reflect average costs. Local refining costs tend to be much lower than those in Europe where labour costs are high and form a significant portion of the fixed cost component; local costs vary between R80 and R105/4E oz, for the purposes of this study costs of R95/oz of 4E PGM are assumed.

Capital costs – CAPEX

The capital investments made into the processing of PGMs from flotation concentrates are very large and as such are a really significant barrier to entry for junior PGM miners. It is not the pretence of this paper to estimate the capital costs of such investments as that is a very detailed and technology specific exercise; however, there are some recent published capital investments that will give some pointers to the order of magnitude of such investments and they are summarized in Table III.

Table III
Process operations investments (capital per unit of capacity per annum)

Investment	Min cost – R millions/ton or oz per annum	Max cost – R millions/ton or oz per annum
Smelter – concentrate tons	R7 000	R9 000
Base metal refining – matte tons	R80 000	R100 000
Precious metals refining – 4E oz	R1 500	R2 000

Economies of scale and technology selection affect the range of capital costs indicated; the above are estimates for greenfield developments, and brownfield developments would be less costly

Inventory costs – pipeline

The very long process times as a result of the technical complexity of PGM processing and recovery mandates a significant holding of high valued metals in the process pipeline. Once established, of course, the inputs are close to the outputs from the process pipeline; however, a significant investment has been made in the bringing the various metal products to the intermediate stages throughout the process. All of this investment has an opportunity interest cost attached to it. These process pipelines reflect not only the typical delays in stockpiling and processing the mainstream of materials but also the circulating loads of recycled residues containing the various metals back to earlier stages in the process or the time taken to ship residues offshore for specialized treatment in another facility.

The significance of this cost is illustrated in Table IV. Table IV is used to calculate the interest costs of the pipeline to a major producer handling 4.0 million ounces of PGMs per annum.

Needless to say, these are very significant costs as they are some four to five times the cash cost of operating a typical PGM refinery.

Purchasers of flotation concentrates need to be prepared for these inventory costs and any new entrants into the field need to be aware of this barrier to entry.

Base metal purity and byproduct revenues

The price that purchasers of flotation concentrates are prepared to pay for base metal units is influenced by the prevailing discounts to the LME price that they receive for their produced form and purity of the recovered base metals.

Nickel production in by the two South African producers (Impala and Anglo Platinum) is usually discounted to the LME price for nickel. Hydrogen reduced briquettes as feed stock for the stainless steel market are normally discounted to the London prices because stainless steel producers are high volume customers and can negotiate a slight reduction in price. In the stainless steel market cathode quality and the size of cut material can also influence the discount to the normal LME price. Premiums are generally paid only for the high quality nickel metal used in the electroplating and battery industries; some Zimbabwean nickel meets these standards. Neither of the major platinum producers makes such high purity nickel. Both Northam and Lonplats sell their nickel production to other nickel refiners as nickel sulphate at a significant discount to the LME price. Premiums and/or discounts in the nickel market can move the nickel price received by a producer away from the LME price by several percentage points under the correct market conditions.

All copper production by the four SA based refiners in the PGM business is produced as cathode. Generally this is poorer quality than the copper produced by SX-EW leach operations in the rest of the globe and as such fairly heavy discounts to the LME copper price are the norm. It is not unusual to see 5–10% discounts being received by the major producers.

Cobalt production in SA is limited to the two major PGM producers, and a premium to the normal LME cobalt price is usually received by Anglo Platinum where cobalt sulphate of a high purity is produced. Premiums are less likely for the production of cobalt metal as a technical or marketing choice.

Sulphuric acid is produced by the two major PGM refiners in SA and sold into the fertilizer market and now uranium leaching market for the most part. The market for sulphuric acid can fluctuate quite significantly such that at times the production is profitable, but in reality the capital invested and the high maintenance costs of acid plants translate into a likely negative return for the purchaser of flotation concentrates over the long-term. It is an investment made only for environmental protection and not for profits. Concentrates with very high sulphur contents such as those from parts of the low grade Platreef are more likely to have penalties applied for the sulphur content than to receive any value for the sulphur.

The refining of copper-nickel mattes to produce copper and nickel metals result in fairly high sulphur disposal costs as well; typically the refined mattes contain 22–23% S and all of this sulphur needs to be removed either as ammonium sulphate (for the hydrogen reduction process used by Impala Platinum) or as sodium sulphate (for the electro-winning process used by Anglo Platinum). While the markets for these materials fluctuate, they are generally sold at little or no profit; sodium sulphate markets in particular have been on the decline in recent years. As a result such by-product sales are not valued in any purchase agreement for flotation concentrates.

Major customer PGM sales discounts

The major PGM producers supported the marketing efforts of the large metal distributors in the early years of the industry by giving discounts to the LME prices and

Table IV
Estimated pipeline costs for a major producer (Concentrate to metal sold)

Metal	Estimate pipeline – weeks	Annual production ozs or tons	Rand per oz or ton price	Inventory value Rb
Platinum	10	2400000	16000	7.38
Palladium	10	1100000	3200	0.68
Rhodium	15	250000	72000	5.19
Gold	10	200000	7200	0.28
Iridium	15	120000	3200	0.11
Ruthenium	15	400000	4800	0.55
Nickel	6	18000	229278	0.48
Copper	6	9000	61729	0.06
Cobalt	6	900	352736	0.04
Total		3.95 moz 4E		14.77
			Yr Cost@12%	1.77
			Cost/4Eoz/yr	R449/oz

continue to support marketing organizations such as the Platinum Guild International. Without this investment the market for PGMs would probably be somewhat smaller. End users of the PGM metals are reluctant pay more for the metals than is reflected in the LME market prices, thus the metal distributors costs and profits must be recovered from the primary producer by way of a discount to the LME. As the markets have grown in volume and larger single contracts are given to major end users, the discount percentage has narrowed but still exists for some metals and for some high volume end users. Depending on the producer and the historical relationships with purchasers, such discounts can be 0–5% of the LME recorded price. In purchasing concentrates for smelting and refining the purchaser must include his discounts given to his end customers as well as his investments in creating markets for the PGM metals.

Deleterious elements – chrome

The major PGM producers who presently buy flotation concentrate for smelting and refining must handle a large array of deleterious elements in the process; Zn, Sn, Pb, Se, Te, As, Sb, Bi, etc. are all nuisance elements that are removed along the processing route. For the most part these elements are disposed of as various compounds in the lined effluent dams at the base and precious metals refinery or these elements accompany slags and dusts at the smelter operation. While these effluents may well be a long-term environmental liability, none of these are currently penalized in purchase agreements simply because all the concentrates from the Bushveld Igneous Complex contain them in small amounts. The only deleterious element that needs special mention is chrome; this is present in all BIC concentrates but at low levels, with the exception of the flotation concentrates from the UG2, MG1/2 or LG6 concentrators. In concentrates produced from these ores the Cr_2O_3 content can range from as little as 1% to as much as 7%. It is not the purpose of this paper to discuss the technical reasons for considering Cr_2O_3 as a deleterious material but small amounts (1–2%) of this spinel mineral in the smelter feed leads to viscous slags, lower recoveries and operational problems in the conventional furnaces. As a result most purchasers of such concentrates impose penalties on the chromite content above 1% Cr_2O_3 as they use conventional smelting technology. Only the Mintek patented ConRoast process, which utilizes DC-arc furnace technology and operates in a reducing atmosphere, has been demonstrated to process the higher chromite containing concentrates easily without blending to reduce the chromite levels in the furnace feed. The financial penalty imposed by purchasers usually varies on a graduated scale with the level of chromite, so it is not possible to assign an easily applied cost or discount factor for chromite. However, financial penalties can be equivalent to a few percentage points of the total metal value and as such are quite significant.

Braemore Resources operates a small demonstration facility in conjunction with Mintek that is designed to treat high chrome feeds (up to 10% Cr_2O_3) which is based upon the patented ConRoast process. In this case Braemore as the purchaser would have no need to impose penalties on the chrome content of any flotation concentrates and as such can offer an advantage to producers of high chrome flotation concentrates.

Typical contracts for PGM concentrate purchase

Various forms of concentrate purchase contracts are possible. Within the SA PGM business there have been numerous purchase agreements signed for PGM concentrates. These take various forms and can contain all or some of the following elements: (1) a treatment charge of RXXX/ton, (2) payment for XX% of the contained metals (usually limited to Pt, Pd, Rh, Au, Ni and Cu), which may be tied to a formula based on free market prices, (3) a refining charge of RXXX/lb of base metal or RXXX per ounce/kg of precious metal for each individual metal, (4) various payment quotational periods up to several months after delivery (Rh is recovered in most operations only after several months) (5) a partial upfront payment (% of total payment) on delivery of the concentrate, and/or (6) penalties for unwanted elements (Cr_2O_3 in concentrates) or for low PGM grades in the concentrates. Minor charges might also be levied for analytical and sampling costs. Where the purchaser refines either residues or final PGM concentrates overseas with a third party these costs are usually passed back to the seller/owner of the concentrates. The most risk-adverse pricing structure for the smelter and refiner is the tolling option in which a simple treatment charge that covers all operating costs, return on capital and a profit margin is charged; however, the tolling refiner must still quote recoveries offered and thus divulge typical recoveries in his operation and take some risk on operational efficiencies. Ownership of the metal remains with the concentrate provider in a tolling relationship and risks are higher for the mine concerned. Most concentrate purchase contracts in South Africa have combined a treatment charge with payment for XX% of the metal so as to partially reduce the purchaser's price risk. Some contracts have been used in which the percentage of metal paid varied with the platinum price.

When forward payments are made to the seller then some of the inventory holding cost is being absorbed by the purchaser, as opposed to being passed on to the seller. Quotational periods that approximate the pipeline time for bringing the various metals to the market and concluding sales are included to protect the purchaser from the risk of serious price movements. In a volatile market, such as is often the case for the PGM metals, the downward price movements can easily destroy any hope of achieving a profit from a particular purchase transaction as the small margin of profit gives no real protection for such volatility. Of course, the alternative is true of price rises but the risks are far too high. Unless risk is reduced in this way and passed back to the seller, then the costs of forward cover on metal prices must be included in the costs of smelting and refining.

Flotation concentrate PGM grade is a very significant determinant of the profit achieved by the purchaser. Low grades cannot attract the same percentage payments as the higher grade PGM concentrates. Most of the SA contracts, which have been based on payment for a percentage of the contained metal have well rewarded the smelter and refiner over the past few years of buoyant metal prices. As the metal prices have zoomed upward, so has the real value of the percentage of the metal value retained by the purchasing smelter and refiner. These two points are well illustrated in the Figures 2 and 3 showing two different price scenarios; two ore types and the maximum percentage of metal payment that can cover the purchaser's total costs.

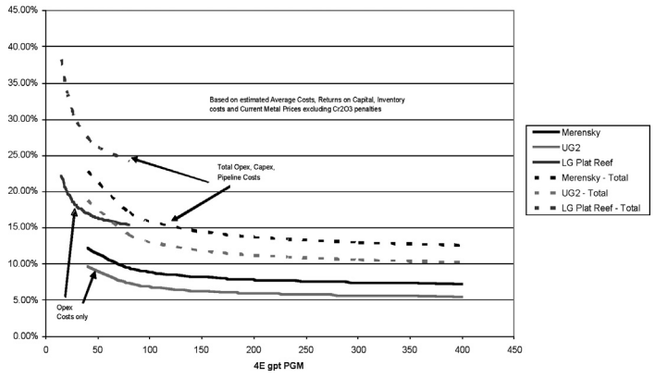

Figure 2. Typical PGM flotation concentrates

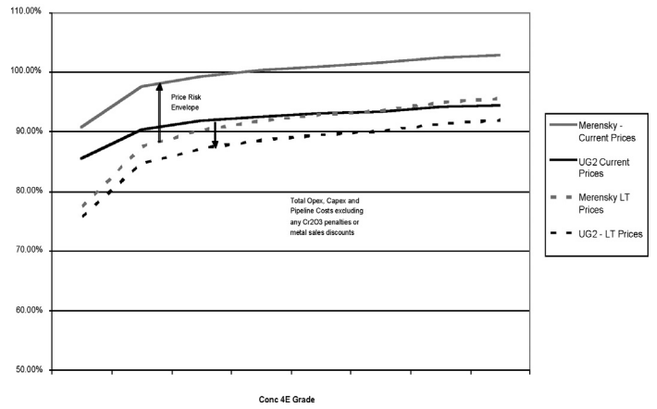

Figure 3. Maximum price

Further risks for the purchaser

The purchaser of flotation concentrates holds the metal in process inventory for quite a considerable time and although in most contracts this price risk over time is compensated by the binding quotational periods, one must recognize that the approximate pipelines are estimates only and in fact the various metals are processed not in discrete packages of metal that flow through to saleable product but rather in a distribution of metal quantities over an extended time period. The price risk associated with this is assumed by the buyer and in a volatile market as is often the situation in the PGM industry these risks can be significant. These risks, are of course, tied to the processing risks as well; the complicated process routes do not always operate smoothly and process disruptions and technical problems in the refining can alter the inventory holding significantly adding to the buyer's costs. Processing problems often result in large residues being recycled to the smelter and re-processed, thus adding to the metal inventory. Process efficiencies within the refining operations must remain high in order for the refiner to maximize his profit but often the high inventories held, metal accounting accuracies and the process complexity make it difficult to measure this metric with absolute accuracy. Sampling and chemical analysis of many of these various products throughout the complex of processing steps adds uncertainty to the absolute value of process inventories, process first pass and ultimate recoveries.

Conclusion

Whilst operating costs of a smelter, base metal refinery and precious metals refinery are a major factor in any offer to purchase a flotation concentrate, an equally significant factor is the capital cost of establishing processing facilities. Important but lesser factors are the holding cost of the metal inventory (notably the platinum and rhodium inventory), the process losses or metallurgical efficiencies, and the sales discounts. At current metal prices these can typically be estimated as follows for Merensky and UG2 concentrates:

Opex costs	10–12% of Metal value
Capex costs	2–14%
Efficiencies	3–4%
Inventory costs	1–3%
Discounts to LME	1–3%

This is not to ignore the major risks of price volatility and the risks of operating a highly technical and complex process involving very high cost metals. In the case of the high nickel Plat Reef ores the opex and capex costs are significantly higher as a result of the low concentrate grades and high nickel contents.

Over time the market will determine the 'fair' price for flotation concentrates as buyers and sellers continue to negotiate for the most advantageous deal and pursue improvements to their products and processes.

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