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Water atomization of PGM-containing intermediate alloys

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Water atomization can be used as an effective intermediate step between the production of a molten alloy from a smelting furnace and a leaching operation. This is especially appropriate for alloys that are not readily crushable. Very fine particles can be produced by the impingement of high-pressure water jets on a molten alloy stream. The use of very fine material as a feedstock for the leaching process allows for considerable savings in residence time, reactor volume, and lower power consumption for stirring.

Results are presented of some atomization testwork that was carried out using alloys that contain Fe-Ni-Cu-Co and have platinum group metals (PGMs) as their most valuable constituents. Factors relevant to the design of a commercial unit are outlined.

Water atomization testwork has shown that alloy particles as small as 20 microns can readily be produced. The relationship between the pressure of the water jets and the size of the resulting particles is such that the mean particle size can be halved by doubling the water pressure (over the range of conditions of interest).

Introduction to the ConRoast process

Mintek's ConRoast process was developed as an environmentally cleaner and more flexible smelting process for the production of platinum group metals (PGM).^{1,2} A DC arc furnace is used to smelt PGM-containing feed materials (such as dead-roasted sulphide concentrates) together with some carbon, thereby forming a small quantity of an iron-rich alloy that is very effective at collecting the PGMs and base metals. The environmental advantage of the ConRoast process is that it dramatically decreases SO₂ emissions compared to the conventional matte-smelting process (by removing essentially all of the sulphur in a continuous enclosed roaster upfront of the smelting). The process is also able to accommodate a wide variety of feed compositions, with no maximum limit on the amount of Cr₂O₃ that can be fed to the furnace, nor any constraint on the minimum quantity of base metal sulphides required. This is very important for the smelting of the increasing quantities of (chromite-rich) UG2 ore currently being mined in South Africa. Furthermore, the ConRoast process does not require intensive cooling systems in the furnace, as the liquidus temperatures of the slag and alloy are very similar, and the operating temperature of about 1 600°C is very manageable.

Since April 2004, Mintek has been operating a demonstration plant³, treating approximately 1 000 tons per month in a 3 m diameter furnace running at a power level of about 1.5 MW. The smelting operation has been in almost continuous operation, having been interrupted only a few times when other research furnace campaigns needed to take precedence. Over the period April 2004 to August

2008, more than 37 000 tons of various PGM-containing feed materials (UG2 concentrates, Merensky concentrates, revert tailings, and converter slag) have been smelted. The quantity of alloy produced is approximately 7.5% of the mass of material smelted. A typical composition of the resulting alloy is shown in Table I. Depending on the PGM content of the feed material, the PGM content of the alloy is typically of the order of 1 000 g/t.

By funding a technology development programme at Mintek, Braemore Platinum Smelters have obtained exclusive rights to the ConRoast process for the production of PGMs for a period of ten years. Braemore have contracted TWP Consulting to carry out various concept studies and bankable feasibility studies. A full implementation of the ConRoast process involves using a fluidized bed roaster (to remove sulphur from the concentrates prior to smelting), a DC arc furnace, and at least a base metals refinery (where the base metals are separated from a PGM-rich residue that provides a suitable feed for a precious metals refinery).

The challenge that is addressed in this paper revolves around finding the most appropriate way of introducing the intermediate alloy product from the furnace into the subsequent leaching process. Especially if the alloy is

Table I
Typical alloy composition, mass %

Element	C	Co	Cr	Cu	Fe	Ni	S	Si	Total
Mass %	0.05	1.3	0.18	4.6	72	14	6	0.05	98

cooled slowly, it is highly resistant to any form of crushing or milling. This is not the first industrial process to face this challenge, and water atomization has previously been used⁴ very effectively to reduce the particle size of an iron-rich alloy to a range that is highly amenable to leaching. Water atomization provides an effective means for the production of small particles, as a way of connecting pyrometallurgical and hydrometallurgical process steps when the alloy would be too hard for milling.

Introduction to water atomization

If a falling stream of molten metal is impinged by jets of water, then it is broken up into droplets which rapidly freeze to form granules (>1 mm) or powder (<1 mm), depending on the composition of the metal alloy, and the water pressure. Classical granulation uses pressures in the range of 2–5 bars (200–500 kPa) and typically produces 1–10 mm size granules. Very large flow rates can be accommodated (in the t/min range), as pumping costs are modest. To make finer powders, one needs higher pressures (we find median size is approximately inversely correlated with pressure), so it is necessary to use more controlled streams, typically from a tundish arrangement instead of a launder as in many granulators, and to run more modest flow rates, typically using nozzles from 3 mm to 30 mm in diameter to give flow rates from 5 kg/min to ~500 kg/min (up to 30 t/h). Pressures range from 20 bars for coarser powders (say 0.3 mm) to 200 bars for finer powders (say ~50 μm)⁵. Elements like sulphur in the melt strongly affect (reduce) the required pressure by reducing melt surface tension.

As shown in Figure 1, the atomized slurry can be pumped, either directly to leach tanks, or to a dewatering system which can deliver either a thickened slurry at ~20% moisture or a damp solid at ~5% moisture. This can then be fed to the leach tanks if the water balance is critical. Drying adds significant energy and cost, but may be done if, for instance, a smelter is selling to a refiner.

Water atomization has been used in the production of iron/steel powders since the 1950s, following its development in the 1930s for copper powders. Median particle sizes of ~50–100 μm are readily produced from high-purity Fe-0.1–0.3%C melts using pressures of ~100

bars (10 MPa). Today, about 80% of the world's iron powder, some 1 Mt/a, is produced by water atomization, typically using ladle sizes from 30 to 110 t and atomizing speeds of 10–50 t/h. Atomizing Systems Ltd (ASL) has supplied scores of atomizers for all sorts of metals, from copper and silver, to Ni, Co, Fe alloys, and has worked with Bateman Engineering Projects on the Chambishi project⁴, which applies atomization to an Fe-Cu-Co alloy for hydrometallurgical refining. In total, 11 projects for atomizing in metal refining applications, including Ag, Au, Pt, Rh, Co, and Ni values, have been supplied. The size of particles requested by clients has ranged from <50 μm to sub-millimetre, and operating pressures have varied from 500 bar (50 MPa) to 20 bar (2 MPa).

Compared to crushing and grinding, atomization has an advantage in lacking any serious wearing parts; the water jets do the work and maintenance costs are modest. The cost of atomization is generally much less than the cost of melting, especially if drying of the product is not necessary, as is normally the case for leaching feeds⁶.

Choice of particle size for leaching

The particle size is important for two reasons:

- The finer the particles, the greater the surface area available to contact the lixiviant; this increases the kinetics of the leaching stage
- The finer the particles, the lower the agitator energy requirement to maintain these in suspension in the leach reactors.

In traditional base metals refining in the platinum industry, it is common for most (80–90%) of the particles fed into leaching reactors to be smaller than 75 μm in size. This enables optimum reaction kinetics, as well as allowing the solid particles to be maintained in suspension in the reactors.

As the particle size increases, extra energy is required to prevent settling of the material. At a relative density around 7, any settling in the reactors is a major concern. Once the solid materials have settled, the only way to clean the reactor is to drain it and dig out the solids. Obviously, if settling were to happen, this would lead to major inefficiencies in the process.

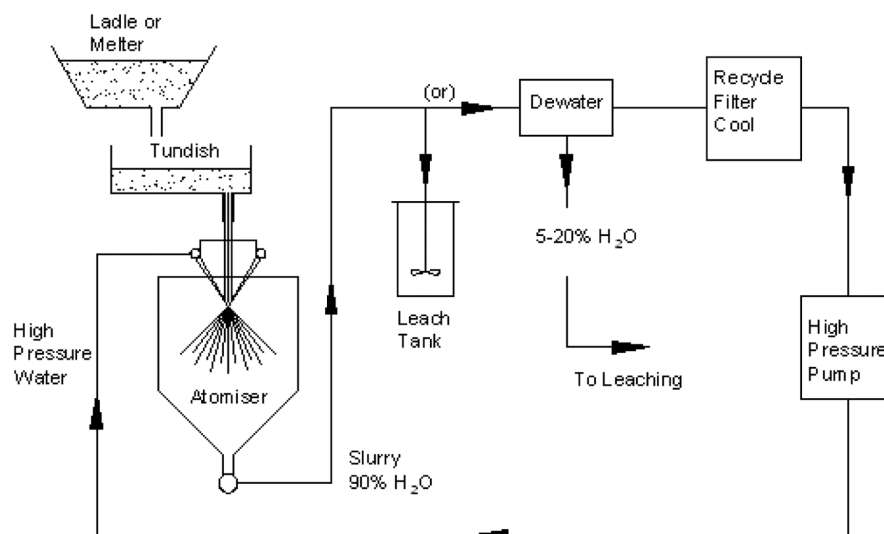


Figure 1. Water atomization—schematic flowsheet

Atomization carried out at a pressure of 200 bar (a representative high-end operation) typically consumes around 20 kWh/t. Bearing in mind that a medium-size smelter (say 10 MW) might produce about 1 t/h of alloy, the energy consumed by atomization can be expected to be less than that used by the multiple 30 kW motors that are used to power the agitators keeping the solids in suspension in the leaching reactors. It makes economic sense to produce the small particle sizes resulting from water atomization at 200 bar pressure, so that the power to the agitators can be kept low. Over the range of particle sizes under consideration, the power to the agitators could increase by as much as 50–60% as the mean particle size increases.

Atomization testwork, February 2008

Approximately 90 kg of typical furnace alloy was shipped in granular form to Atomizing Systems Limited in Sheffield, UK, and water atomizing testwork was carried out in February 2008. Work was carried out on a very small-scale system, with a 25 kg melter and an atomizer typically rated for 5–10 kg/min melt flow rates. In ASL's experience, the results obtained on this scale are typically rather coarser than those achievable on a larger scale, say over 50 kg/min. A 4 mm diameter nozzle was used for all tests, and melt flow rates were 5–7 kg/min.

The first attempt to melt the raw alloy granules showed it to be very difficult to induction-heat such small pieces in the 3 kHz furnace, so an iron lump was needed to get it started. Thereafter, a heel was kept in the melter to facilitate melting. The final run was done with ~90% of iron added to a heel, to show the effect of the changed sulphur content. This also required an increase in pour temperature, as the alloy melting range depends strongly on the sulphur content. The use of a heel made mass-balance checks very

difficult, but experience in many projects with far more valuable alloys indicates that losses are minimal in production.

As shown by the bottom line in Table II, the alloy shows an almost perfect inverse relation between pressure and median size, with D_{50} in mm $\times P$ in bar being ~4.39–4.52 for all three trials with the same alloy composition. The last trial, with about one tenth of the alloy content, showed a higher value of 5.28, and we would expect a sulphur-free alloy of this composition to be over 6. Figure 2, shows the data for the high-sulphur alloy corresponds to the equation:

$$D = 4\,496 / P$$

where D is the median particle size in microns, and P is atomizing pressure in bars.

The fairly high sulphur content of this alloy thus makes it relatively economical to produce powders with median sizes in the 20–40 μm range.

The particle size distributions resulting from 50 bar, 100 bar, and 195 bar pressures are shown graphically in Figures 3 to 5.

Table II
Operating results

Run No.	W187	W188	W189	W190
Alloy	Shot +~15% Fe	Shot	Shot	Heel +~90%Fe
Water pressure	100 bar	195 bar	50 bar	190 bar
Pour temp.	1 551°C	1 550°C	1 540°C	1 622°C
Malvern D_{50} μm	44.1	22.5	90.5	27.8
Malvern D_{90} μm	121.6	67.3	238	98.4
Malvern D_{10} μm	14.2	7.8	28.3	8.8
Sieve % <45 μm	54.2	86.2	37.5	65.0
Sieve D_{50} μm	41	~21	58	32
Sieve Std Dev	2.05	2.0	2.07	2.5
D_{50} mm $\times P$ bar	4.41	4.39	4.52	5.28

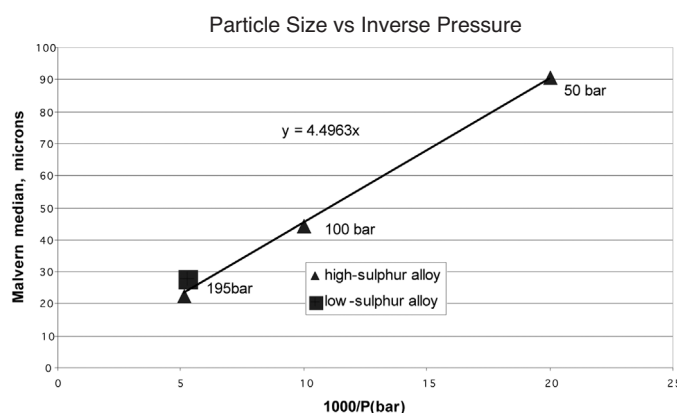


Figure 2. Effect of (inverse) pressure and composition on powder median size

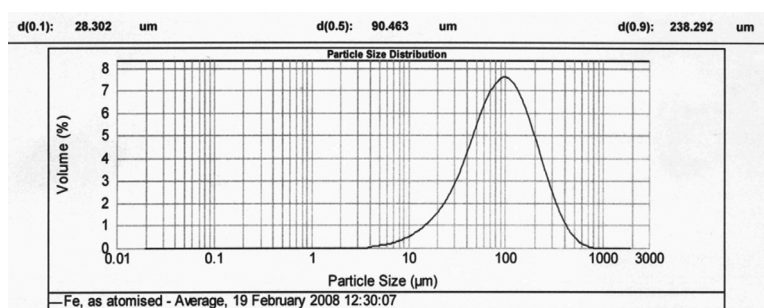


Figure 3. Particle size distribution from 50 bar pressure, $D_{50} = 90 \mu\text{m}$

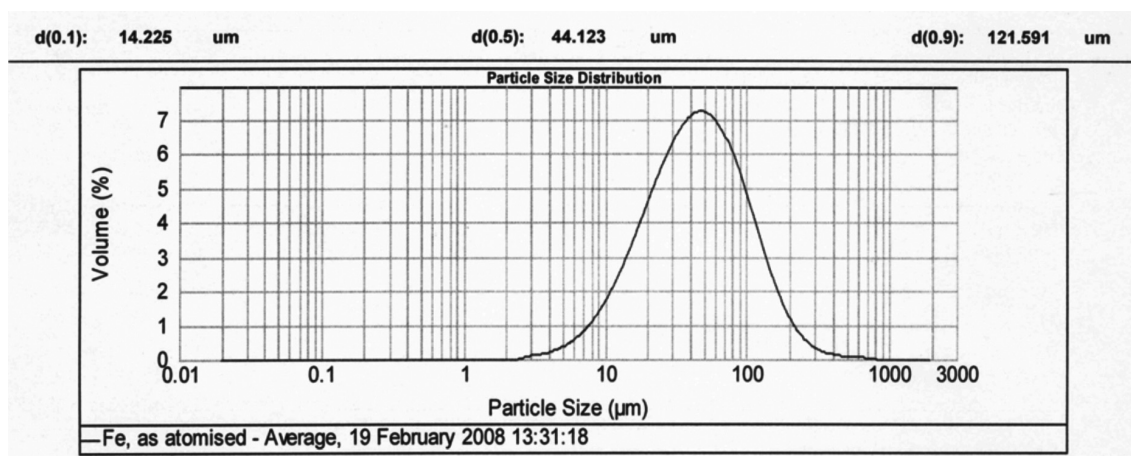


Figure 4. Particle size distribution from 100 bar pressure, $D_{50} = 44 \mu\text{m}$

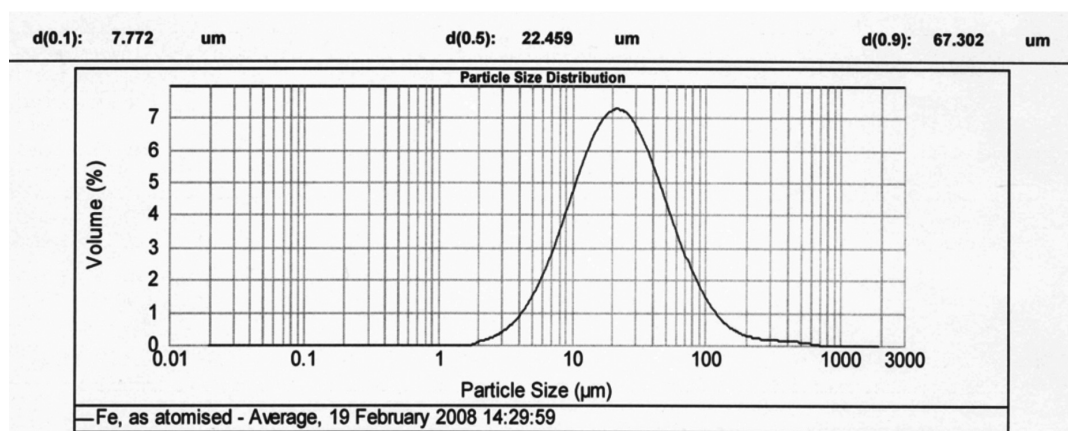


Figure 5. Particle size distribution from 195 bar pressure, $D_{50} = 22 \mu\text{m}$

Conclusions

Water atomization testwork has shown that alloy particles as small as $20 \mu\text{m}$ can readily be produced. The relationship between the pressure of the water jets and the size of the resulting particles is such that the mean particle size can be halved by doubling the water pressure (over the range of conditions of interest).

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1978—Joined Bateman as a Civil Engineer

1981 to 1987—Construction and Project manager mainly on Iron and Steel and Petrochemical related projects

1987 to 1992—Project Manager and Deputy Construction Manager Moss gas on-land project

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