A new gravity concentrator to enhance fine flotation performance

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The Mozley multi-gravity separator (MGS) has proved more efficient at separating fine particle sizes than conventional gravity separators. It is a viable alternative for cleaning existing froth flotation circuit concentrates, or removing valuable precious metals from these streams.

Gravity concentrators, as the name implies, have normally worked with the single 'g' force available from the earth's gravitational field. Past inventions[1,2] have attempted to push the performance of gravity concentrators to recover finer minerals at higher throughput, by multi-decking and careful consideration of the flowing film concentration process. However, the idea that finer particles could be recovered more successfully by increasing the 'g' force is attractive.

Over the past 10 years or so, a number of inventors spread around the world (Kelsey in Australia, Knelson in Canada and others in China and elsewhere) have come up with solutions to the problem of harnessing the higher 'g' forces that can be generated by fast rotation within their own concentrator.

The Cornish group at Richard Mozley Limited started to look at this problem. They decided to keep to a thin, flowing film-type concentrator; one in which the fluid film containing the fine particles could still be subjected to a shearing action; and a number of prototypes were developed. It was found that finer particles could be recovered and that the applied 'g' force did not have to be very large: for example, 5μm cassiterite could be recovered by pinning under a force of between 10g and 20g.

Now experimenters had to decide on the best physical embodiment of the basic idea. It was decided that the machine should work continuously, if possible, as previous inventions by Mozley had the drawback that they were discontinuous and therefore more complicated. The problem of how to achieve counter-current movement of the pinned high-density particles was solved by using a series of angled scrapers; improved washing of the concentrate, as it moved through a washing zone, was also achieved.

It was clear that a very exciting new machine was possible. From the marketing standpoint it was decided that the best way to introduce it was to make a pilot or laboratory-scale machine that could be sold immediately. This would introduce the new technology to the industry and pave the way for the mine-scale units. The latter would require more careful development because of the greater demands made through continuous operation in an often hostile environment.

During the first stages of development, covering the period 1987 to 1990, the pilot unit progressed rapidly to its present form (the C900 MGS, see Figure 1), and a series of prototype mine-scale units (C902 Twin Drum) were made and tested. These units were not for sale but were hired out to mine environments to test both the validity of the metallurgical results obtained by laboratory testing on the smaller machine, and also to see how the machine stood up mechanically under continuous operation. A design audit was also commissioned during this period, which sanctioned the basic design but led to considerable improvements in detail.

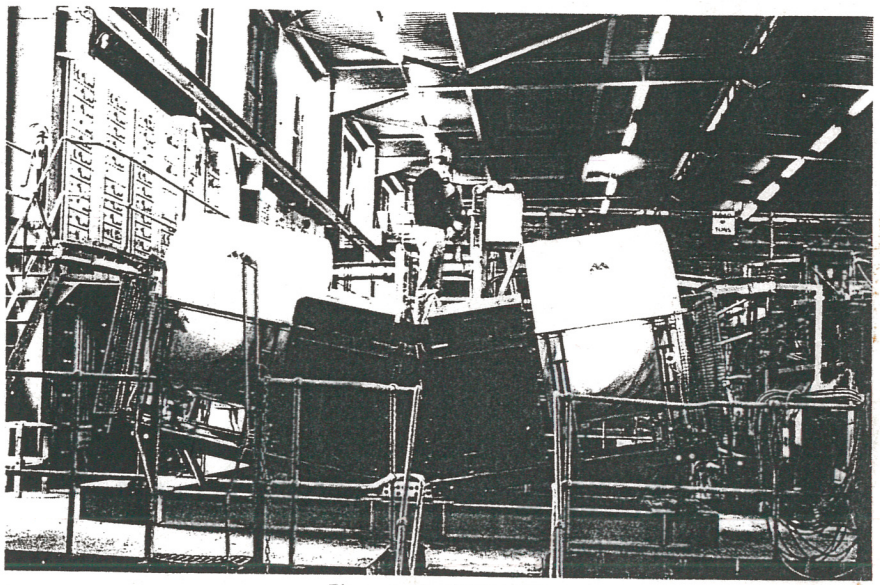

Figure 1. The C900 MGS.

By 1991, the first production machine was built, the MkIV, which was successfully commissioned in trials at Beralt Tin & Wolfram, as well as Somincor in Portugal. Consequently, with only minor modifications, the present design of the machine evolved.

How the C902 MGS came to play an important part in productivity improvement at Carnon Consolidated's Wheal Jane Mill is an interesting story, because it shows the validity of the original marketing theory, and also how co-operation between differing groups plays such an important part.

The first programme of tests were conducted by Rick Roddick,[3] a final-year student at the Camborne School of Mines, under the direction of Dr Barry Wills. This work showed that the performance of the flotation column could be greatly improved by the MGS, not only in terms of grade, but also recovery. These results were so spectacular that they engendered great interest at the mine, which sought independent corroboration.

Further testwork was carried out at Richard Mozley's laboratory and the results showed complete agreement. It was decided that the old No. 1 prototype (which was at the mine) should be pressed into service to confirm the results on a plant scale. This was soon done and, although the old machine was mechanically unreliable, its use did prove that the mine-scale unit was able to produce superior metallurgical results.

While this was going on, Carnon Consolidated and Richard Mozley negotiated the building and installation of a new machine, with the appropriate payment terms. Within 14 weeks it had been built and switched with the old one (in February 1993), and Mozley agreed to provide Carnon with in-house mechanical training. The new machine has achieved 100 per cent availability (the mine operates under 10-day, 24-hour operation, every 2 weeks) and the payback has been rapid (3 months). Mozley gained a very satisfied customer and a showpiece installation for the many overseas visitors that journey down to Cornwall to see them.

Meanwhile, more than 50 of the C900 pilot units have been sold to laboratories and mines worldwide. These units will be disseminating the technology that will lead to the successful introduction of a new machine. It will be capable of integration into flotation circuits, where previously no gravity concentrators could be applied successfully, as well as giving an alternative to the shaking table for conventional gravity concentration plants. In-house metallurgical optimisation testwork by Carnon's metallurgists has been ongoing since the machine was installed.

Description of ore and flowsheet

South Crofty ore consists mainly of cassiterite-rich veins in granite host-rock. The veins dip sub-vertically and are mined by a mixture of longhole and shrinkage stope methods. The main gangue minerals are quartz, haematite, tourmaline, fluorspar, chlorite, wolframite and scheelite. The liberation size of cassiterite is 180 microns.

Run of mine ore (-150mm) is crushed in a conventional two-stage crushing circuit to -12mm and stored on a fine-ore stockpile. The -100μm crusher fines report to spiral classifier overflow and are pumped to the mill. Minus 12mm fine ore is milled, initially, to 80 per cent, passing 180μm using an

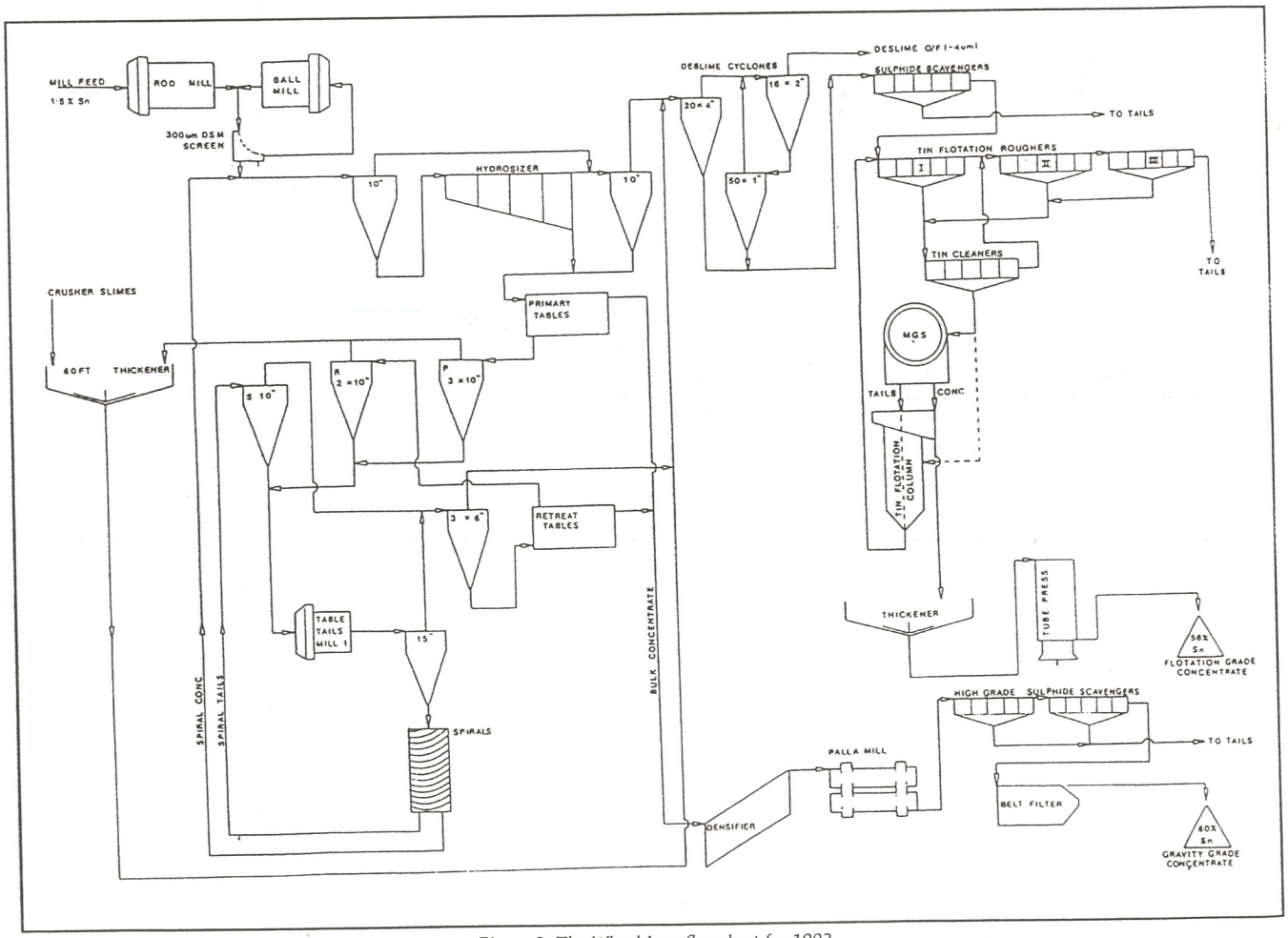

Figure 2. The Wheal Jane flowsheet for 1993.

open-circuit 170kW rod mill, followed by a 260kW variable-speed ball mill, in closed circuit with DSM screens. Classification is carried out using hydrocyclones and Stokes' hydrosizers. Classified feed reports to Holman shaking tables, where 65 per cent of the cassiterite is recovered to a bulk concentrate assaying 58 per cent combined tin and sulphur. Residual arsenopyrite and pyrite, in the dewatered bulk concentrates, are subsequently reground and removed using conventional bulk sulphide flotation. The cleaned cassiterite concentrate, reporting to flotation tailings, is dewatered on an EIMCO horizontal vacuum-belt filter, to a moisture content of 4 or 5 per cent, and typically assays 60 per cent Sn.

Primary shaking-table tailings and middlings are combined, dewatered in hydrocyclones and reground in a 260kW variable-speed ball mill to 80 per cent passing 125μm in closed circuit with hydrocyclones, Vickers spirals and more Holman shaking tables. A further 5 per cent of the cassiterite in mill fresh feed is recovered, to the same bulk concentrate grade as specified above, giving a total gravity recovery of 70 per cent.

Holman shaking-table performance falls dramatically below 15μm in size and, as a consequence, this finer material reports to the tin flotation circuit. Tin flotation circuit feed is initially deslimed using 4in, 2in and 1in hydrocyclones in order to reduce tin flotation feed -6μm content to about 10 per cent by weight. The deslimed feed is initially passed through a bank of sulphide scavenger froth flotation cells, where sulphides are removed using sodium ethyl xanthate as collector, MIBC as frother, and sulphuric acid as a pH modifier. The small amount of sulphides removed report to the tailings dam and the sulphide scavenger tailings report to the tin flotation circuit.

The flotation feed is initially conditioned at pH 5.2, using sulphuric acid as pH modifier and with the Engelhard dispersion/depression chemical mixture added. Sulphosuccinamate collector is stage dosed down the rougher bank of cells. Rougher concentrates are conditioned at high mixer speed to promote breakdown of gangue minerals from the rougher concentrate froth, and sodium silicofluoride is dosed as fluorspar depressant. After one stage cleaning, the cleaner froth reports directly to the Mozley MGS for final cleaning to smelter specification (currently 50 to 55 per cent Sn). MGS concentrates are thickened and pressure filtered to 7 per cent moisture, for bulk shipment. Tin flotation tailings are used for beach construction around the tailings dam. An additional 16 per cent recovery of tin in mill feed is recovered by tin flotation/MGS, and this is predominantly cassiterite in the -45+6μm size-range.

	Tin float feed %Sn	Tin float tail %Sn	Tin float conc %Sn	Tin float stage rec %
Column flotation	0.575	0.227	50.16	60.79
MGS 16.07.1992-18.11.1993	0.558	0.187	55.45	66.71
MGS 09.08.1993-18.11.1993	0.480	0.140	55.83	71.01

Table 1. Summary of MGS performance.

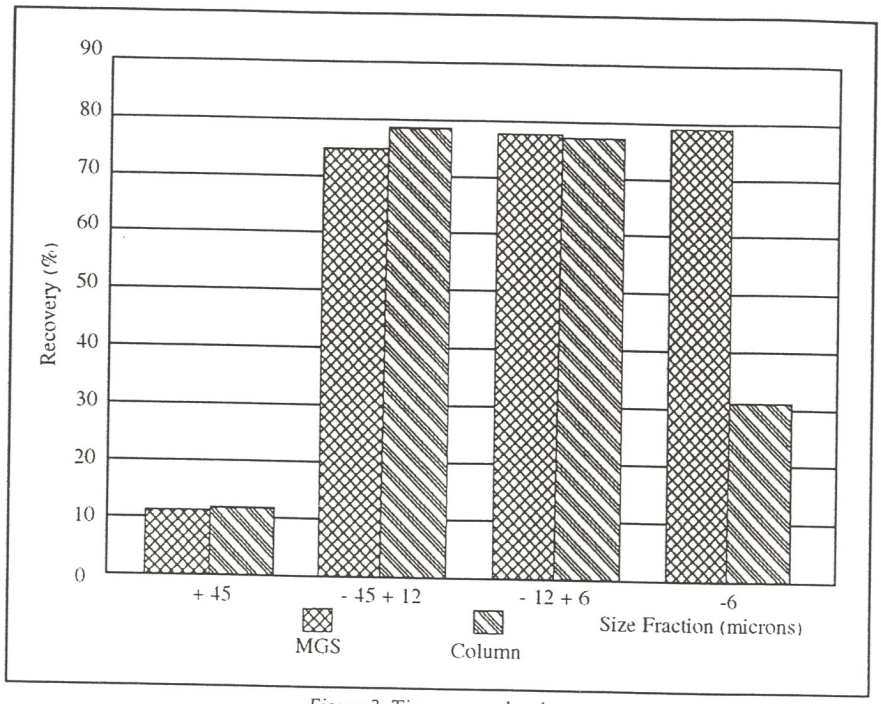

Figure 3. Tin recovery by size.

Plant testing of the mine-scale MGS

The prototype MkI mine-scale MGS was moved into position above the existing column after suitable steelwork had been fabricated for the base, and the existing column feed pump and motor were upgraded to allow it to pump up the extra head required to gravity-feed both drums of the MGS through a splitter-box arrangement. MGS tailings were directed to the head of the second bank of roughers, with MGS concentrate reporting direct to the flotation concentrate thickener. Feeding the MGS tails back to the cleaner cells, as with the column, led to an unacceptably high recirculating load of fluorite.

Trial testing of the MGS commenced in July 1992. Due to the success of these trials, an order was placed for the new MkIV machine, which was installed and commissioned in February 1993. Table 1 summarises the results obtained compared to the column running on Town's water. As the trial progressed, optimisation of the MGS continued. In particular, the drum speed was steadily increased, together with the tilt angle and wash-water flow-rate.

From Table 1, significant improvements in overall tin flotation concentrate grade and recovery have been achieved, compared to the column running on Town's water. An economic analysis, taking into account changes in other factors that affect recovery, indicate a payback of approximately three months.

Figure 3 (above) and Tables 2 and 3 (next page) highlight how the MGS is far more selective and efficient at recovering -6μm cassiterite than the column. Despite higher -6μm cassiterite recovery, the MGS concentrate product is less slimy due to lower entrained gangue content (see Figure 3), and a consequential reduction in transport costs has been achieved due to lower weight split to concentrate and lower cake moisture (7.3 per cent moisture compared with 8.9 per cent with column flotation).

Size (µm)	Concentrate wt(%)	Concentrate %Sn	Tailings wt(%)	Tailings %Sn	Calculated feed wt(%)	Calculated feed %Sn	Sn distn	% weight recovery to conc	% Sn recovery to conc
+45	0.91	47.51	53.75	0.11	51.87	0.13	14.78	0.04	11.23
12	15.45	61.15	18.55	0.20	22.24	0.79	40.20	0.97	74.90
6	45.76	63.26	18.74	0.17	18.26	0.77	31.92	0.95	77.79
–6	7.88	59.30	8.96	0.16	7.63	0.75	13.10	1.00	78.76
	100.00	61.85	100.00	0.14	100.00	0.44	100.00	0.49	67.44

Table 2. Tin flotation circuit size/recovery date with the MGS.

Size (µm)	Concentrate wt(%)	Concentrate %Sn	Tailings wt(%)	Tailings %Sn	Calculated feed wt(%)	Calculated feed %Sn	Sn distn	% weight recovery to conc	% Sn recovery to conc
+45	2.98	41.05	49.02	0.15	48.72	0.17	16.8	0.05	11.81
+12	39.10	61.24	21.10	0.20	21.22	0.92	59.6	1.18	78.52
+6	35.74	43.17	18.74	0.16	18.75	0.69	26.2	1.23	77.09
–6	22.19	18.62	11.23	0.53	11.30	0.76	17.4	1.27	31.14
	100.00	44.73	100.00	0.21	100.00	0.49	100.00	0.63	57.41

Table 3. Tin flotation circuit size/recovery data with the column.

Despite tin flotation feed grade reducing, since the MGS was commissioned, as a result of coincidental higher gravity circuit recovery, both tin flotation stage recovery and enrichment ratio have been increased, clearly demonstrating how gains in both recovery and selectivity have been achieved over the column (see Table 1 and Figure 4).

Figure 5 clearly demonstrates how both enrichment ratio and recovery have been increased since the MGS has been installed.

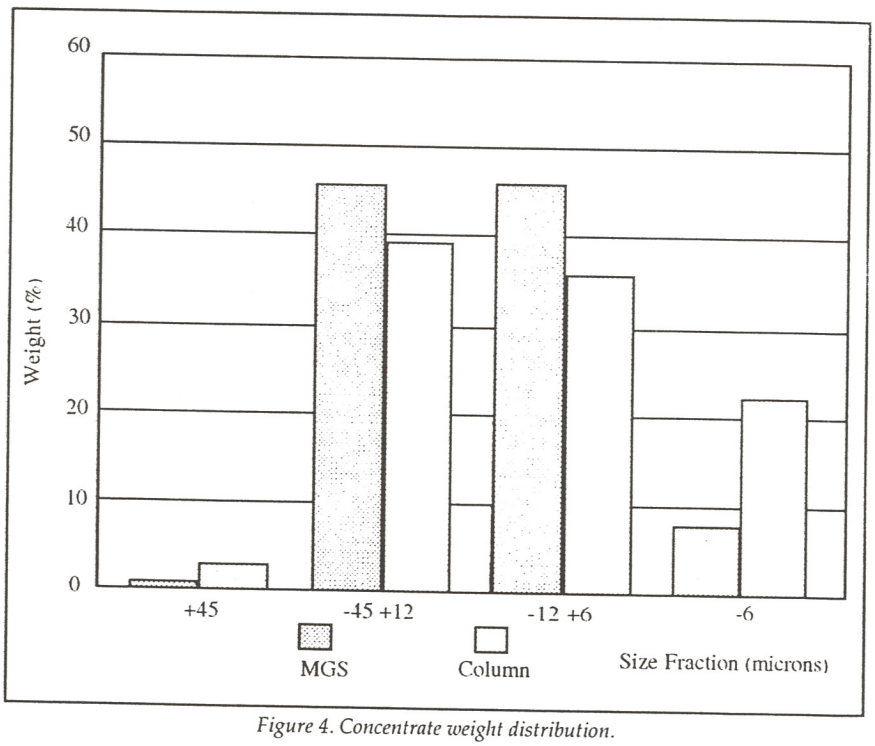

Figure 4. Concentrate weight distribution.

Effects of operating parameters on MGS performance

To establish the effects of the various operating parameters on MGS performance, a series of tests were carried out on a laboratory MGS using samples of current mine-scale MGS feed. Using a set of base parameters, the effects of pulp density, drum speed, throughput, wash-water flow-rate and shake intensity were investigated.

Throughput. The most important factor governing throughput is the drum diameter. However, for a fixed drum diameter, as throughput is increased, grade improves at the expense of recovery, as shown in Figure 6. An estimation of the scale-up factor for the laboratory MGS is approximately 16 or 17:1.

Feed-pulp density. The effect of feed-pulp density is shown in Figure 7 and is one of the most important factors governing MGS performance. As density increases, there is a steady increase in recovery, while concentrate grade remains fairly steady, but drops appreciably as the density increases over 1200g/1. Efforts are being made to maintain feed densities as close to this optimum as possible.

Wash-water flow-rate. Wash water is an important factor governing concentrate grade, with higher feed densities requiring higher wash-water flow-rates. The effect of wash water is shown in Figure 8. As wash water increases, grade improves at the expense of recovery, and this is the major form of short-term control.

Drum speed. Together with feed-pulp density, this is the most important factor governing MGS performance, and its effects are shown in Figures 9 and 10. An increase in rotational drum-speed will reduce concentrate grade and increase the weight split and recovery of heavy mineral to concentrate. This is illustrated in Figure 9 for the laboratory MGS. Figure 10 shows the effect of drum speed on stage recovery and concentrate grade for the mine-scale MGS, and clearly shows how stage recovery increases almost linearly with drum speed, while the concentrate grade starts to fall off at about 135rpm. The current drum-speed

on the mine-scale version is 126rpm, with a maximum 180rpm possible.

Feed W/S ratio. Figure 11 shows the effects of the feed water to solids ratio, related to the wash-water flow-rate and the feed-pulp density, which clearly demonstrates that the feed-pulp density is the most important variable of the two. The wash-water flow-rate is only used to control concentrate grade.

Shake intensity. Shake intensity is varied by adjusting the shake frequency and the amplitude. The effect of shake is to impart an additional shearing action on the particles, which aids the separation process. Results showed that decreasing the shake amplitude from 15mm to 10mm on the laboratory MGS decreased concentrate grade for an equivalent recovery. When a 20mm shake amplitude was tested on the mine-scale MGS, drum recovery was significantly lower at equivalent throughputs. A 15mm shake amplitude is currently used, and a shake frequency of 5.8cps has been found to be satisfactory.

Tilt angle. The angle of tilt used will depend upon the nature of the material, with high-density mineral requiring a larger angle. Increasing the tilt angle will increase throughput slightly, but too large an increase will reduce recovery. The current angle of tilt is 10° for each drum.

Control of MGS feed-pulp density and throughput needs to be improved. A redundant 25ft-diameter thickener is to be recommissioned as a storage vessel for MGS feed, which, in conjunction with adequate instrumentation, will provide a means of controlling both feed-pulp density and throughput at optimum setpoint. Size/recovery testwork needs to be carried out to

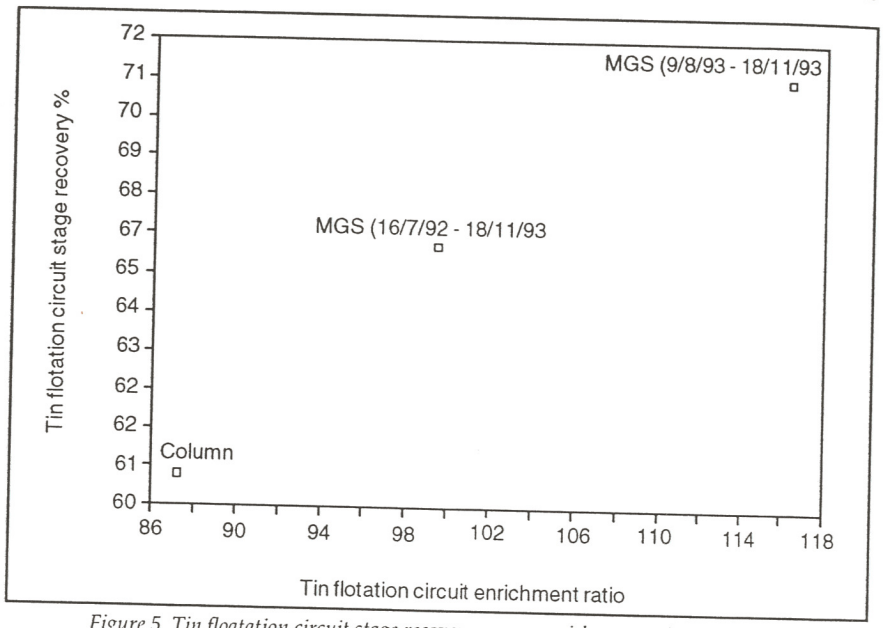

Figure 5. Tin floatation circuit stage recovery versus enrichment ratio: comparison of column flotation and MGS.

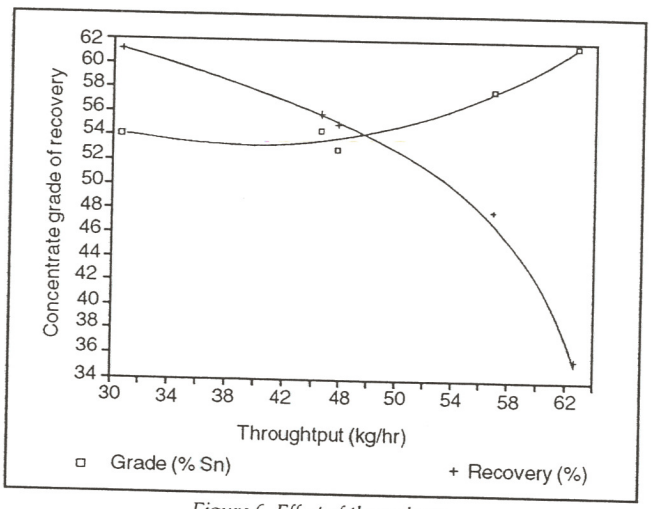

Figure 6. Effect of throughput.

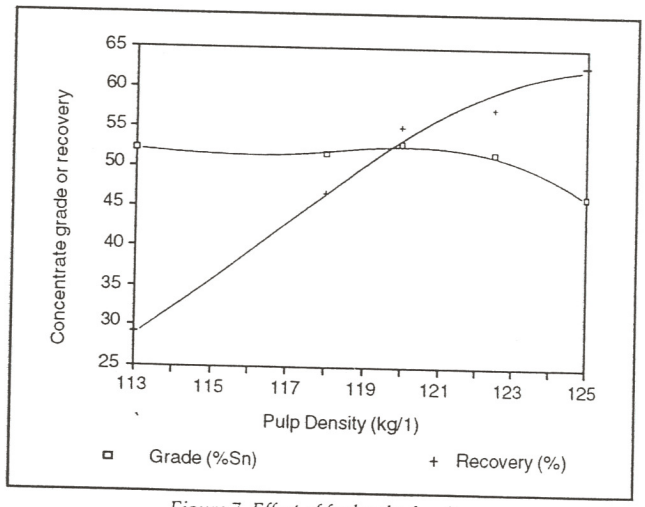

Figure 7. Effect of feed pulp density.

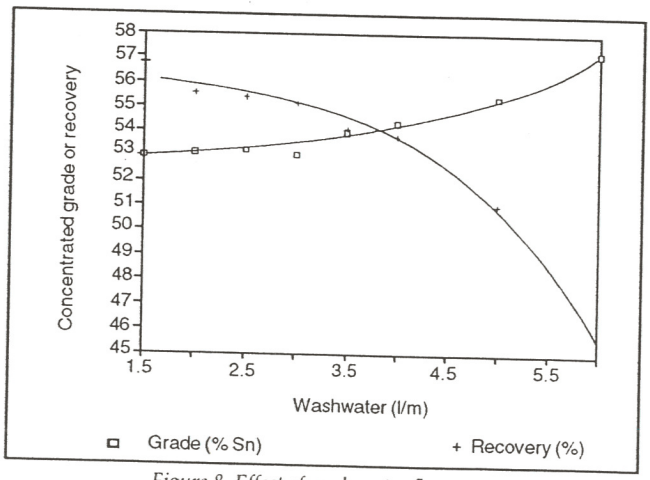

Figure 8. Effect of wash-water flow-rate.

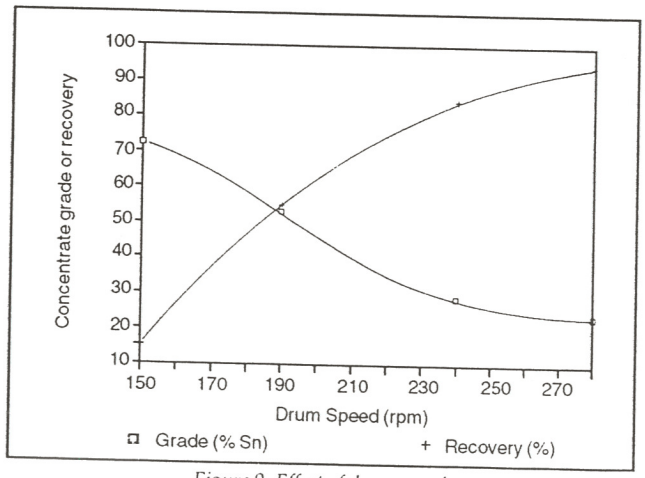

Figure 9. Effect of drum speed.

establish more information on -6μm cassiterite recovery.

Conclusions

The MkVI MGS has significantly improved Carnon's economic performance of its tin flotation circuit, and payback is estimated to take less than four months.

The company has the ability to produce more than 60 per cent Sn concentrate grades from tin flotation, if required. This was not possible using column flotation.

The company has realised cost savings by turning off Town water from the cleaner froth flotation circuit, which was a prerequisite of the column flotation circuit.

Plant availability has been 100 per cent. Initial indications are that scraper life is approximately six or seven months, equating to 1mm of wear for every 164 dry tonnes of concentrate produced. □

Acknowledgements

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R Mozley MBE, ACSM, FIMM, FEng is chairman of Richard Mozley Limited and spends a good deal of his time inventing new mineral processing devices. He was formerly managing director of the company from its formation in 1978 until 1993.

M P Hallewell BSc, FIMM, graduated in 1981 and then worked as a metallurgist at the Western Deep Levels Gold Mine, before joining South Crofty Mill, Redruth, Cornwall in 1984. In August 1986, he joined Carnon Consultancy, and since 1991 he has been metallurgical superintendent for Carnon Consolidated Limited, based at the Wheal Jane Mill.

J W G Turner BSc, MSc, MIMM, CEng, graduated in 1984 and worked as a plant metallurgist for Gencor until 1988, in the gold and platinum divisions. After commissioning the new Sao gold plant in Brazil, he went to work in Venezuela at the Revemin gold tailings retreatment plant. In 1991, he came to England to take his MSc and joined Carnon Consolidated Limited as assistant metallurgical manager at the Wheal Jane tin plant in Cornwall.

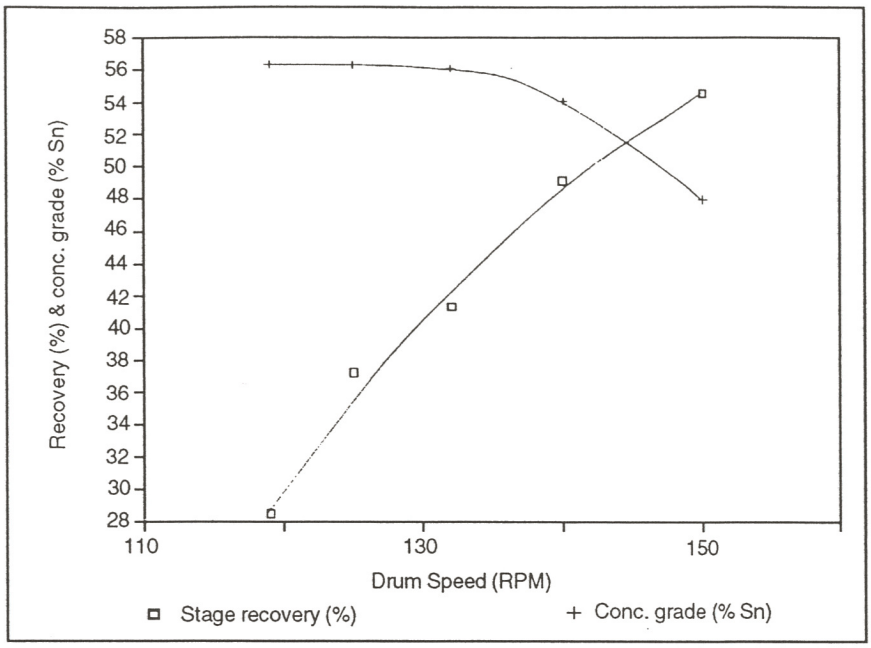

Figure 10. C902 plant-scale MGS: stage recovery and concentration grade versus drum speed.

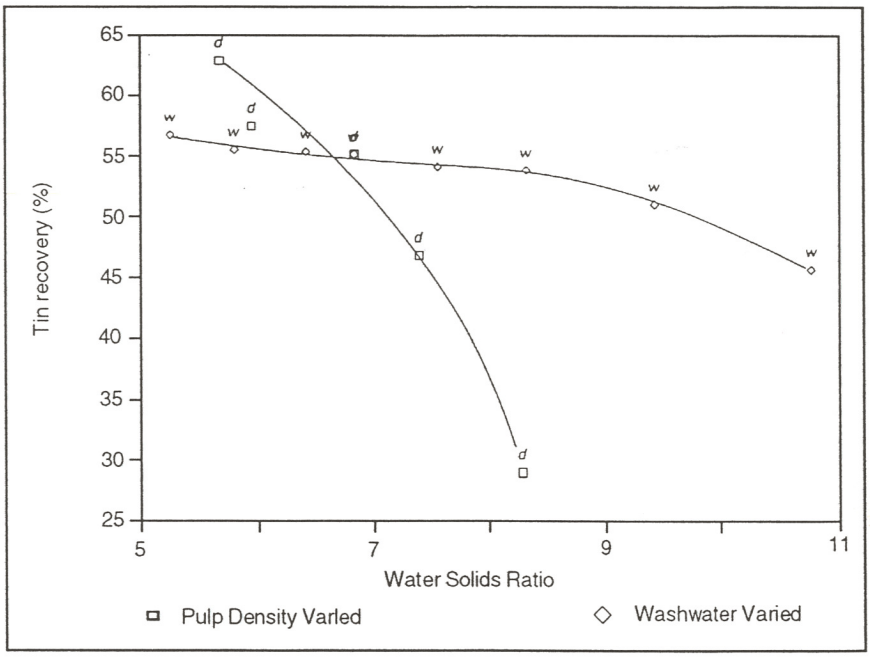

Figure 11. Laboratory MGS testwork: tin recovery versus water:solids ratio.

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