Computer Simulation at Wheal Jane, Cornwall

K. A. Lewis,* A. Wells,† and P. Tucker*

Abstract

Mathematical modelling methods were used at Wheal Jane, to investigate the sensitivity of the Stokes hydrosizer to changes in the operating variables, with the view to improving the process efficiency. The major conclusion was that the hydrosizer was overloaded. The results indicated that throughput and spigot densities were the most sensitive variables. The model predictions demonstrated that a significant improvement in classification efficiency (both in sharpness of separation and in fines misplacement) could be achieved by (i) increasing hydrosizer capacity and (ii) increasing spigot 1 density to its practical limit. Based on these predictions, a decision was made to install a second hydrosizer in parallel with the first. Subsequent testwork on the new circuit validated the predictions and confirmed that an improved efficiency had been achieved. From monitoring plant performance for 4 month periods before and after the change, it was established that a significant increase in overall tin concentrate grade had resulted. Further improvements are now expected from optimizing the hydrosizer/primary tabling circuit (as an integral unit), that is by tuning the table operations to more fully exploit the now better classified feeds. Recommendations, in this direction, will be provided by computer simulation methods.

This paper reports on the computer simulation techniques used in this study: their basis and their application to optimizing both unit processes and larger blocks of the process flowsheet. The mathematical models of the Stokes hydrosizer and the shaking table are discussed briefly and their scope and limitations are examined within the context of this investigation. Model predictions and sensitivity analysis results are presented and are compared with the measured data. The technical improvements are discussed in detail and the improved production statistics are analysed in terms of the financial benefit gained by Wheal Jane. Finally, the advantages of using computer simulation and other computer-based techniques, in promoting enhanced plant performances, are examined.

Introduction

Warren Spring Laboratory is currently working with industrial partners, Carnon Consolidated (Cornwall UK) and Beralt Tin and Wolfram (Portugal), on an EC sponsored project to develop software for the minerals industry aimed toward enhancing plant performance. The bulk of the software produced has been in the form of mathematical models of individual unit processes (eg, spirals, hydrosizers, shaking tables etc,) and a flowsheet simulator. The simulator allows these individual units to be linked together forming flowsheets, paralleling what happens on a processing plant.

Simulation and modelling techniques offer many potential benefits to both the plant engineer and plant designer. The conventional approach to optimizing or modifying an operating plant is that planned changes are based upon available process data or, perhaps, on comparisons with similar plants. Often, the information available to the engineer will be incomplete. So the decisions made will avoid major risks and, where ever possible, are aimed at minimizing disruption to the plant. Also, because of

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* Warren Spring Laboratory, Department of Trade and Industry

† Carnon Consolidated

limitations on the time that can be allocated to the solution to any given problem, the range of alternatives that can be explored is often severely restricted and the optimum solution is rarely achieved in practice. Simulation and modelling methods enable the engineer and/or designer to assess the potential merits of several operational strategies before implementing any real change on the plant. The techniques must be seen as tools intended to enhance the decision-making, enabling more cost-effective decisions to be made. The techniques are intended to supplement rather than replace professional expertise.

The software developed in this collaborative project is now installed at the plants of the industrial partners and this paper describes the financial benefits already gained by Carnon Consolidated at Wheal Jane tin processing plant in Cornwall, UK.

Gravity concentration plays an important part in the Wheal Jane flowsheet, (see Wells[6]). A single Stokes hydrosizer is used to classify the feed for the shaking table operations. However, for some time metallurgists had not been fully happy with the performance of the hydrosizer. Fines entrainment was particularly acute. The reason had not been fully established although several contributory causes had been identified, one being that the hydrosizer was treating a high tonnage of relatively fine feed that contained a significant fraction of very fine material. It was decided to use the hydrosizer model to address this problem aiming to optimize, if possible, its performance.

The results of this simulation exercise, detailed later, indicated that improved hydrosizer performance could be best obtained by reducing the hydrosizer throughput. This gave Wheal Jane the impetus to change its flowsheet, and install a second identical hydrosizer running in parallel to the existing one. After monitoring the new flowsheet for four months it was evident that the hydrosizer performance had dramatically improved giving Wheal Jane real financial benefits of around £120,000 extra revenue per year.

However, this is not the end of the story. Improved hydrosizer performance has caused a change in the loadings of the primary tables. Were these now running below their best? The solution will be provided through an optimization of the hydrosizer/primary tables as an integral unit. This study, which forms the next part of the simulation exercise, is now being carried out at Warren Spring Laboratory.

Details of the work at Warren Spring Laboratory with respect to modelling and simulation of mineral processing plant have been published in previous papers, Tucker *et al,*[1, 2] Mackie *et al*[3] and Manser.[4] Therefore, it is not proposed to discuss this work in great detail here. However, a brief outline of the basic gravity model (GMODEL), the simulator (GSIM) and two of the models (hydrosizer and shaking table) incorporated in the package are included for completeness.

Modelling and Simulation

GMODEL is a general purpose physical separation model designed initially for gravity separation devices. The software has a modular structure. The main block or model skeleton contains the input/output routines, the optimization mathematics and the standard mineral processing calculations. All the device specific information, that is essentially the model equations, are contained within a device module. These modules can be linked in with the model skeleton as required. Obviously a different device module is required for each individual separating device. Separation performance within the model is characterized by material transfer coefficients (T), which describe the probability of material being transferred from the feed to an individual output stream. These coefficients are formulated in terms of material properties such as size and specific gravity. Separation performance is represented by:

$$A_{ij}\, T_{\kappa ij} = B_{\kappa ij}$$

where A_{ij} is the mass flow of the ith density fraction of the jth size fraction in the process feed. $T\kappa i_j$ is the material transfer coefficient describing the partition to the κth output stream ($B\kappa i_j$). A single functional form (Fp) is used to describe separation performance over the normal range of operating conditions.

$$T\kappa i_j = Fp\,(i, j, V1, P) \qquad \text{main model equation}$$

and

$$P \;= \text{function}\,(V2) \qquad \text{auxiliary model equation.}$$

V1 are machine operating variables dealt with explicitly in the main model. Their effect on performance is known sufficiently well to set up precise mathematical relationships. V2 refer to other operating variables whose effects on performance are less well defined. P represents a set of model parameters.

To model an existing plant, performance of that plant must first be measured. Model calibration, that is definition of the parameter set P, is achieved by minimizing the differences between the measured performance data and model transfer coefficients through optimization of the parameter values. After the main model is calibrated in this way, the determined parameter set will define the exact relationship in the auxiliary model. Predictions for a new set of operating conditions can then be made directly from the model equations.

GSIM is a process simulator which parallels on a computer what happens on a plant. The individual device modules in GMODEL can be linked, individually or as banks, together to form complete flowsheets or blocks of a more complex flowsheet. In order to use the simulator the flowsheet under examination must first be described in terms of the actual devices used and how they are linked together. Secondly, the feed or feeds to the circuit must also be described. This is done in the same way as for GMODEL, that is in terms of their size and specific gravity distributions, massflow rates and pulp densities. Lastly, the problem needs definition. In its simplest form GSIM can be used to predict the performance of an existing plant under a given set of conditions. However, GSIM can also be used as a design tool to optimize the circuit operating conditions in order to best achieve a pre-set goal. This goal is normally one of two options, either a mineral recovery can be optimized whilst maintaining a minimum acceptable grade or mineral grade can be optimized whilst maintaining a minimum acceptable recovery. In addition other constraints may be imposed such as target massflows and pulp densities of the feed per device or block of devices.

The mathematics within GSIM are complex and are described in detail in Mackie and Tucker.[5]

A model of the Stokes Hydrosizer

Within the hydrosizer model the physical laws of settling are combined with a probabilistic approach to give the probability of particles in each size/specific gravity category reporting to a particular product. For the purposes of modelling the hydrosizer the best method of expressing the results was as depletion coefficients (T^*). The T^* for a spigot is the probability of particles that have not reported to a preceding spigot reporting to that spigot. Within the model T^* is expressed as the sum of two functions:

$$T^* = F1 + F2$$

where F1 models the transfer due to settling and F2 models entrainment of fines.

F1 represents the S-shaped distribution curves of the hydrosizer and is adequately described by the Rosin-Rammler equation:

$$F1 = 1 - \exp\frac{[-x^{a} \ln 2]}{d50}$$

where x is the particle size.

As well as the particle specific gravity, both the teeter water flow rate and the particle residence time greatly affect the d50. These factors are included in the model by the following expression for d50:

$$d50 = \frac{P1(f(\text{teeter water}) + f(\text{residence time}))}{(SG - PD_{K})^{a}}$$

PD is the pulp density of spigot product K, and

$$a = \frac{P2}{d50(SG - PD_{K})^{0.5}}$$

P1 and P2 are model parameters as described earlier.
The entrainment of fines is expressed as:

$$F2 = P3\ W_{K}\ f(\text{size})$$

where f(size) is a function that decreases rapidly as particle size exceeds 100um. W_K is the volume of water leaving spigot K and P3 is another model parameter. For more details of the Stokes hydrosizer model see Mackie *et al.*[3]

A model for shaking table operation

The separation performance of a shaking table for a given mineral ore is determined by the positioning of stream cutters and the operating conditions eg, feed mass flow rate, pulp density, deck angles etc. The approach used to develop the model was to attain representative distribution profiles along the discharge edges of the table for sets of different operating conditions. This was done by examining small discrete samples taken along this edge. Each individual sample was divided into a number of size fractions by standard sieve analysis. Each size fraction was subdivided further into a number of density fractions by heavy liquid separation. A series of distribution curves were so defined which can adequately be modelled by the equation given below. This function fits all of the transfer curves studied to date.

$$T = 1 - \exp\frac{(-(X - Xo)^{Y})}{X1}$$

T represents the material transfer coefficient describing the partition to the Kth output stream. X is the fraction of the length of the total table discharge edge defined by the stream cutter. Xo, Y and X1 are compound variables which are functions of size, specific gravity and model parameters. Development work focusing on how these functions vary with operating conditions is currently being completed.

More detailed information on the shaking table model can be found in Manser[5] who reports the preliminary work done on the model development. The model described in this paper represents a development of Manser's work.

First stage simulation

Plant operators at Wheal Jane were concerned at the less than optimum performance of the hydrosizer. The products, especially that from spigot 1, continuously showed an unacceptable amount of fine entrained material. The cause had not been fully identified but a major contributory factor was the high throughput of relatively fine feed (with a top size of approximately 350um) which contained a significant proportion of very fine material. The manufacturer's d50 setting for the discharge from spigot 1 was, in fact, greater than the feed top size.

To overcome this problem various strategies were proposed. It was decided to use the hydrosizer model to evaluate these strategies and their effects before any real changes were made. By doing this, unnecessary plant disruption was avoided.

In order to use the model it was first necessary to calibrate the model for the current Wheal Jane operation, that is to calculate the model parameter set P. The mass flow rate and pulp density of each flow stream (ie, feed, 4 spigots and overflow) was measured. In addition a sample of each stream was collected in order to determine the size and specific gravity distributions by size and heavy liquid analysis respectively. These data were then used as model input to regress to the model parameter set.

Once the parameter values were defined the model was used to predict the effect of increasing the rate of teeter water additions. Both the model and previous plant experience indicated that this would do little to reduce entrainment of fines. After the teeter water had been investigated the model was used to predict the effect of changes to the mass flow rate and the discharge density of the spigots. The results are summarized in Figure 1a–1d. The shaded areas on the four graphs represent the misplacement of fines caused by the lower than recommended spigot densities. The 'hatched' areas show inefficiencies due to unacceptably high feed rates.

The modelling exercise showed clearly that decreasing the throughput would increase classification efficiency and that increasing the spigot densities would reduce the amount of misplaced fines. Undoubtedly, the hydrosizer was overloaded.

Action at Wheal Jane

The model results prompted immediate action at Wheal Jane. Initially, the throughput to the hydrosizer was reduced by removing extra −50 um material from the feed. This was done by installing a 4 inch instead of a 3.5 inch vortex finder on the 10 inch cyclone feeding the hydrosizer. Spigot densities were also increased. This did improve matters a little but the feed rate required further reduction to achieve the optimum hydrosizer performance. With flowsheet as it stood this was not possible. The only real answer was to install a second hydrosizer running in parallel to the first. This modification was made.

The changes in the hydrosizer's performance curves were remarkable, with greatly improved classification efficiencies. Figure 2 shows the size distribution curves for spigots 1 and 2 before and after the changes. These changes led to an improvement in the concentrate grades produced by the plant.

Looking at plant performance as a whole, rather than the localized gravity circuit, table 1 shows plant statistics for the four months prior to the changes and the four months after. As Wheal Jane processing plant also treats the ore mined at South Crofty results for both ores are given.

Table 1. Plant production statistics at Wheal Jane
Wheal Jane ore

	Feed grade	Conc grade	Tin recovery	Economic recovery
Before	0.86	42.40	73.92	58.72
After	0.85	43.41	74.19	59.29

= circa £4500 per month extra revenue

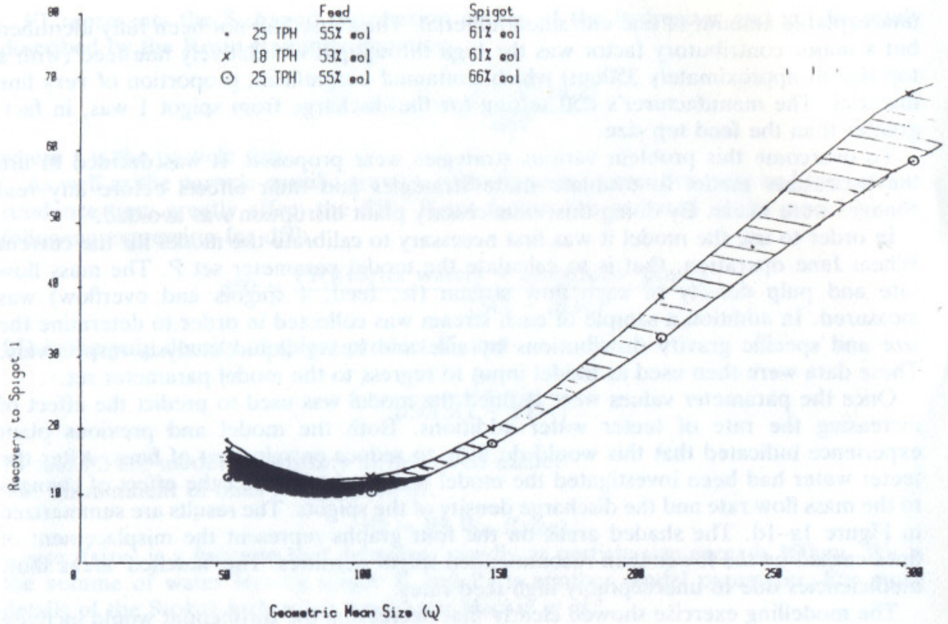

FIGURE 1a
Spigot 1

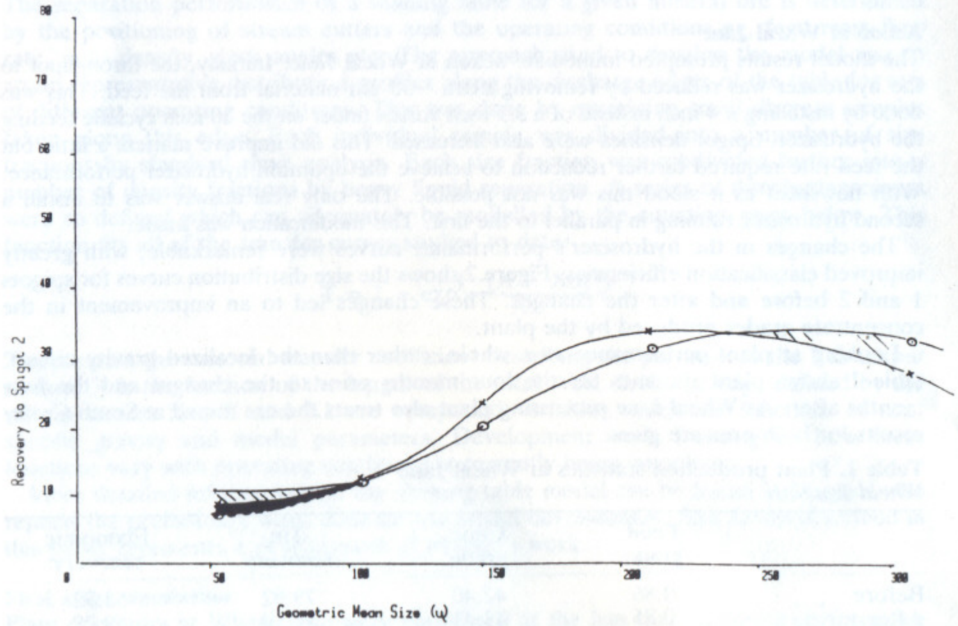

FIGURE 1b
Spigot 2

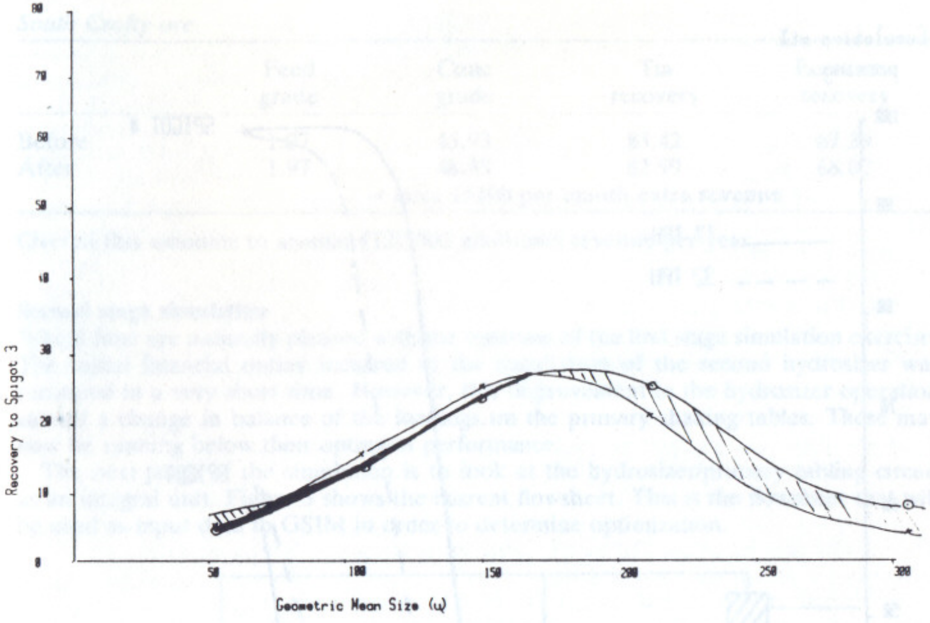

FIGURE 1c
Spigot 3

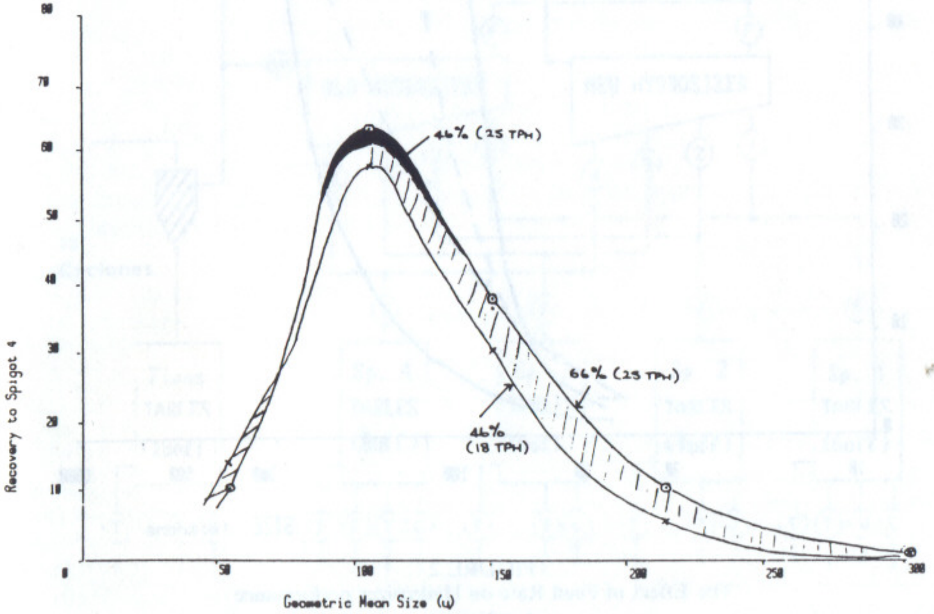

FIGURE 1d
Spigot 4

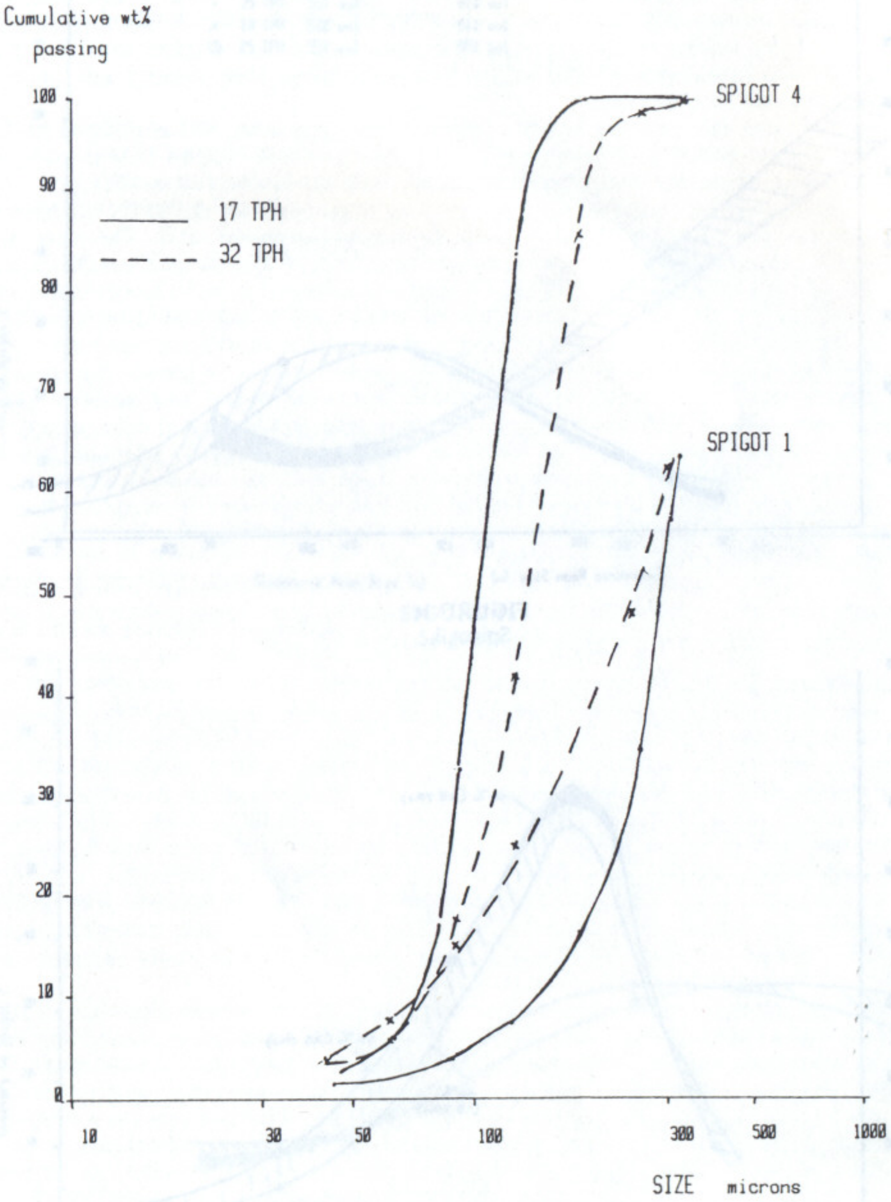

FIGURE 2
The Effect of Feed Rate on Hydrosizer performance

South Crofty ore

	Feed grade	Conc grade	Tin recovery	Economic recovery
Before	1.97	45.93	83.42	67.39
After	1.97	48.33	82.99	68.02
		= circa £5100 per month extra revenue		

Overall this amounts to around £120,000 additional revenue per year.

Second stage simulation

Wheal Jane are naturally pleased with the outcome of the first stage simulation exercise. The initial financial outlay incurred in the installation of the second hydrosizer was recouped in a very short time. However, this improvement in the hydrosizer operation caused a change in balance of the loadings on the primary shaking tables. These may now be running below their optimum performance.

The next stage of the simulation is to look at the hydrosizer/primary tabling circuit as an integral unit. Figure 3 shows the current flowsheet. This is the flowsheet that will be used as input data to GSIM in order to determine optimization.

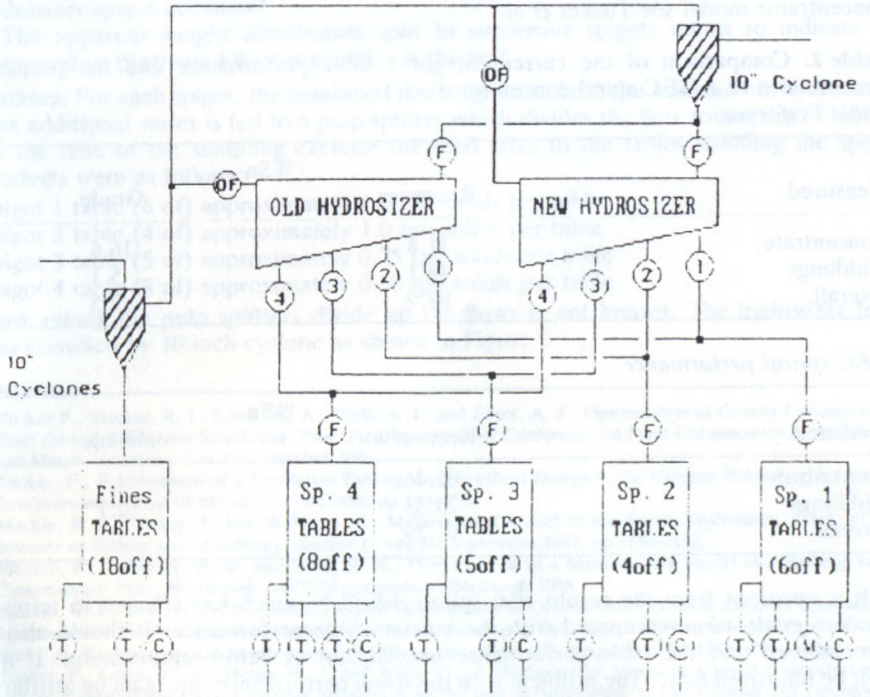

FIGURE 3
Flowsheet of the Hydrosizer/Primary Table circuit

Initially, however, model parameter sets for both the hydrosizers and each of the tables must be derived. Each of the four hydrosizer spigots feeds a series of tables; the spigot flow being divided by a pulp splitter. Spigot 1 currently feeds six tables, spigot two four tables, spigot three five tables and spigot four eight tables. Fortunately it was not necessary to study each individual table but just one example for each spigot. It was assumed that as all the tables fed by one spigot were set up similarly they were all operating in a similar manner.

Each of the chosen tables and each of the hydrosizers were sampled and their flowrates and specific gravities measured as described earlier. GMODEL will be used together with the appropriate model to calculate the parameter sets. These, together with the description of the flowsheet feeds and circuits will be used as input data to GSIM. The GSIM goal is to optimize recovery at a minimum acceptable grade. In addition the number of tables per hydrosizer spigot will be optimized. At the time of writing, this part of the work is in abeyance pending the finalization of the shaking table model.

Wheal Jane also posed the question as to whether or not spiral concentrators would be more effective than shaking tables at upgrading the flow from spigot 1. In the past a great deal of work has been done by Warren Spring Laboratory at Wheal Jane in order to develop a spiral model. A considerable amount of data, and therefore several relevant parameter sets, had been collected. These were used to address this question. The results are presented below in table 2. For further information on the spiral concentrator model see Tucker *et al.*[7, 8]

Table 2. Comparison of the current Spigot 1 table performance and the predicted performance of a GEC spiral concentrator

Table Performance

	%Sn	
Measured	Recovery	Grade
Concentrate	41.8	16.6
Middlings	48.1	5.1
Overall	89.9	7.5

GEC spriral performance

	%Sn	
Predicted	Recovery	Grade
Concentrate	62.46	4.7
Middlings	29.33	2.7
Overall	91.79	3.5

It is apparent from the results that spirals would be much less efficient in terms of product grade when compared with the current table performance. It should also be remembered that the table performance quoted here is before optimization. It may well be improved later. The problem with the spiral performance can again be attributed to the high percentage of fine material present in the spiral feed both inherently from the ore itself and due to the fines entrainment still remaining. Although the model application, in this case, did not lead to any improvement, the example serves well to illustrate one of the prime features of the method. A possible alternative solution was able to be tested quickly, without the need for additional (expensive) testwork, capital expenditure or causing any plant disruption.

Conclusion

Computer simulation techniques have successfully been used to optimize the performance of the hydrosizer at Wheal Jane. Wheal Jane is now reaping the rewards and based on this accomplishment further improvements in the gravity circuit by using these methods are planned.

Simulation and modelling techniques have an important role to play in the day to day problem solving on plant where they can be successfully used to solve real industrial problems of design, optimization and help to give the user a better understanding of the complexities of a modern commercial plant in a cost effective manner. Computer based methods allow all the possible solutions to a problem to be explored in depth, quickly, without major risk, expenditure or plant disruption.

Acknowledgement

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Discussion

I. R. M. Chaston: Could the authors give the feed rates to the tables handling the hydrosizer spigot products?

The apparent weight distribution split to successive spigots seems to indicate an unnatural or pretreated feed material – is this so?

Authors: For each spigot, the combined discharge from both the new and old hydrosizers plus additional water is fed to a pulp splitter which divides the flow to a series of tables. At the time of the sampling exercise the feed rates to the tables handling the spigot products were as follows:

Spigot 1 table (6 of) approximately 1.0 tph solids per table
Spigot 2 table (4 of) approximately 1.0 tph solids per table
Spigot 3 table (5 of) approximately 0.75 tph solids per table
Spigot 4 table (8 of) approximately 0.50 tph solids per table

How evenly the pulp splitters divide up the flows is not known. The hydrosizer feed was classified by 10 inch cyclone as shown in Figure 3

References

[1] Tucker P., Mackie, R. I., Lewis, K. A., Wells A. P. and Elliot, A. J., Optimization of Gravity Concentration Plant through Computer Simulation. Proc. First International Conference on Plant Enhancement in the Mining and Metals Industries. London, October 1986.

[2] Tucker, P., Development of a Simulation Package for Flowsheet Design in the Minerals Processing Industries. Scandinavian Journal of Metallurgy 15 (1986) pp 143–150.

[3] Mackie, R. I., Tucker, P. and Wells, A. P., Mathematical Model of the Stokes Hydrosizer. Trans. of the Institute of Mining and Metallurgy. Section C. vol 96, September 1987, pp c130–c136.

[4] Manser, R. J., Barley, R. W. and Wills, B. A., Development of a Mathematical Model of a Shaking Table Concentrator. Proc. Nineteenth APCOM symposium, Pittsburgh 1986.

[5] Mackie, R. I., and Tucker, P., Simulation and Optimization of Gravity Concentration Circuits. International Symposium on the Mathematical Modelling of Metals Processing Operations. 29 November 1987, pp 147–160.

[6] Wells, A. P., Metallurgical Improvements at Wheal Jane, Cornwall, England, 1984–1988. This volume.

[7] Tucker, P., Lewis, K. A., Hobba W. J. and Wells, D., A Mathematical Model of a Spiral Concentrator, as part of a generalized Gravity-process Simulation Model and its application at two Cornish Tin Operations. XVth International Mineral Processing Congress. Cannes 1985.

[8] Tucker, P., Lewis, K. A. and Hallewell, M. P., Computer Modelling as an aid to Optimization of the Primary Spiral Circuit at South Crofty Limited. Trans. of the Institute of Mining and Metallurgy. Section C. vol 96, June 1987, ppc87–c92.