Computer Simulation at Wheal Jane, Cornwall

K. A. Lewis,* A. Wells,t 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 test work 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

* Warren Spring Laboratory, Department of Trade and Industry
† Carnon Consolidated
These coefficients are formulated in terms of material properties such as size and specific gravity. Separation performance is represented by:

\[ A_i T_{ij} = B_{ij} \]

where \( A_i \) is the mass flow of the \( i \)th density fraction of the \( j \)th size fraction in the process feed. \( T_{ij} \) is the material transfer coefficient describing the partition to the \( k \)th output stream (\( B_{kj} \)). A single functional form (\( F_p \)) is used to describe separation performance over the normal range of operating conditions:

\[ T_{ij} = F_p (i, j, V_1, P) \]

and

\[ P = \text{function (V2)} \]

**Auxiliary model equation.**

\( V_1 \) 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. \( V_2 \) 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 difference 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, massflows 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.

**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:

\[ T^* = F_1 + F_2 \]

where \( F_1 \) models the transfer due to settling and \( F_2 \) models entrainment of fines.
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 Xl 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 Manser5 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>
<thead>
<tr>
<th>Table 1. Plant production statistics at Wheal Jane</th>
<th>Feed grade</th>
<th>Conc grade</th>
<th>Tin recovery</th>
<th>Economic recovery</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheal Jane ore</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Before</td>
<td>0.86</td>
<td>42.40</td>
<td>73.92</td>
<td>58.72</td>
</tr>
<tr>
<td>After</td>
<td>0.85</td>
<td>43.41</td>
<td>74.19</td>
<td>59.29</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>circa £4500 per month extra revenue</td>
</tr>
</tbody>
</table>

...
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.
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 flows rates 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>
<thead>
<tr>
<th>Table Performance</th>
<th>Measured</th>
<th></th>
<th>Predicted</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Recovery</td>
<td>%Sn</td>
<td>Grade</td>
</tr>
<tr>
<td>Concentrate</td>
<td>41.8</td>
<td>16.6</td>
<td></td>
</tr>
<tr>
<td>Middlings</td>
<td>48.1</td>
<td>5.1</td>
<td></td>
</tr>
<tr>
<td>Overall</td>
<td>89.9</td>
<td>7.5</td>
<td></td>
</tr>
<tr>
<td>GEC spiral performance</td>
<td>Recovery</td>
<td>%Sn</td>
<td>Grade</td>
</tr>
<tr>
<td>Concentrate</td>
<td>62.46</td>
<td>4.7</td>
<td></td>
</tr>
<tr>
<td>Middlings</td>
<td>29.33</td>
<td>2.7</td>
<td></td>
</tr>
<tr>
<td>Overall</td>
<td>91.79</td>
<td>3.5</td>
<td></td>
</tr>
</tbody>
</table>

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) textwork, 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 problems 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

The work was supported by the DTI and through the second and third EC Raw Materials Programmes.

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