Process Control

Chairman: Dr R. E. ROBINSON

Rapporteur: Dr R. P. COLBORN

Papers:

The simulation of crushing plants by W. J. Whiten

Simulation of multi-component flotation plants by B. K. Loveday and G. R. Marchant

Computer control of flotation at the Ecstall concentrator by M. P. Amsden C. Chapman and M. G. Reading

Model for the design and control of flotation plants by R. P. King

In presenting his paper Dr W. J. Whiten outlined the basic concepts on which the control model was based and emphasized the fact that empirical models based as much as possible on theory were used to simulate each unit of the crushing plant. The final parameters of each model were computed using data collected from the plant. Unfortunately, the system did not permit accurate extrapolation but was successful when operating in the region from which the parameters were calculated.

He concluded from the results of the test work that the crusher amperage was a critical parameter and that the utilization of the model gave a 15 per cent increase in the plant output. This was because the model predicted that a marginally fine grind would provide a significant increase in throughput. Dr Whiten elaborated on what constituted the multiple spline regression, explaining that it was a least-squares curve-fitting technique in one or more dimensions, where the calculation of coefficients in analytic expressions was replaced by the calculation of typical points on a very smooth curve called a spline function. The emphasis was placed on the shape and value of the curve or curves instead of on the coefficients as in analytic regression. A spline function was the line drawn between all points constituting the data set.

Dr B. K. Loveday commented that the simulation was unusual in that the optimum throughput was considered to be the maximum throughput, which, surely, was limited by the crusher size. He also emphasized the importance of the interaction between both crushing and grinding circuits and added that in practice the optimum operating conditions were inter-dependent. Dr Whiten replied that in the case of the plant under consideration, the crushing process was not, in fact, the limiting operation.

Mr C. E. Clifford indicated that the model was being used to simulate a number of crushing and grinding circuits at Mount Isa Mines. He reported that the model simulated the circuit satisfactorily for primary and secondary gap settings of 0,625 in. to 0,375 in., but that adjustment had to be made to the model parameters for gap settings of 0,250 in. to 0,125 in.

In reply to a question from Dr D. M. Hawkins, Dr Whiten said that he preferred to use low-order splines with smaller segments rather than high-order spline functions with large segments.

Mr A. Weiss asked what investigation was being directed towards grinding and flotation and also asked whether a model was used. Dr Whiten replied that he thought it essential to achieve satisfactory crushing plant control in order that work on a grinding plant control circuit could be completed. Initially, an analogue computer had been used but the system was currently totally digital. He added that it was expected that a major effort would be made on the development of flotation control.

Mr E. Buchalter asked what the stability was of the iterative procedure when recycle streams were met with, and also which criteria were used to ensure convergence. Dr Whiten replied that little difficulty was experienced with low circulating loads, but that for high loads 30 or more iterations had proved necessary. The criteria for convergency adopted were based on the fractional difference between the i-th and $(i+1)$-th intersection.

Mr Robin asked whether the model had been used to control a different grinding circuit and, if so, whether the actual model had to be altered to do so, or whether only changes in the parameter values were sufficient. The reply to this was that the control system had been installed at Broken Hill and that slight adjustments had been made to both the model and the parameter values. The system had proved to be less satisfactory in operation compared with the Mount Isa control circuit.

Mr Amsden, in introducing his paper described the use of a Honeywell H316 computer for direct control of the 10 000 ton/day Ecstall copper-zinc flotation concentrator. X-ray analysis combined with reagent control is used in the copper and zinc float plants and the grades and recoveries control is based on smelter economics.

The result of installation of the control cycle had been an immediate increase in the grades and recoveries, particularly on the copper concentrators. This improvement resulted in an increase in revenue equivalent to $1 500 000 over a period of two months which effectively repaid the investment in equipment.

Dr Whiten congratulated the author on his achievement. He noted that the flowsheets showed that each control variable was taken to its limit before the next variable was altered, and asked if this policy could be improved upon. In reply, Mr Amsden said that actual control of each variable could be adjusted, depending upon the prevailing conditions.

Mr Weiss commented that this was perhaps the most significant use of computer control on a flotation-concentrator circuit and that the authors had implemented a system which really seemed to be paying off. A further commendable feature was that the authors had utilized fully the user's

requirements and had effectively overcome the psychological barrier that operators have when dealing with computers. He also wondered whether the authors had tried using old data when designing the system. Mr Amsden replied that the system was based entirely on old data and that the collection of data specifically for design of the system had been unnecessary.

Mr Reid queried the ability of the system to cope with input feed variation and suggested that wide fluctuations would influence the control strategy adopted. Mr Amsden replied that there was control on the grinding circuit feeding the flotation circuit and that any fluctuations were dealt with adequately by the control system as there were long time lags in the circuit.

Mr Joffe asked what operating system and application software were used, and where the software had been developed. Mr Amsden replied that Honeywell assembler language was used and that all programming was done at Ecstall.

Dr Whiten said that at Mount Isa they insisted on high-level languages as the availability of these languages affected the speed of implementation of control systems.

Dr Loveday in presenting his paper discussed the facilities which had been at his disposal at the Kennecott Copper Corporation plant. He emphasized that the control strategy was based on improving revenue and thus the area of economic significance was the copper content of the tailings.

In order to develop the model he had performed tracer tests on one of the two concentration plants which processed 110 000 tons of ore per day. These tests were used to determine lags in the system. He had also used the information obtained from on-stream X-ray fluorescence analyses, and had developed a steady-state control system which optimized operating conditions based on an economic evaluation rather than a feed back control system aimed at giving a constant rate. The model predicted that an increase in the circulating load could result in an increase in recovery. These increases were relatively small, being of the order of a fraction of a per cent, but the equivalent revenue accruing from this fractional increase was substantial.

Dr Whiten asked why the authors had complicated a very simple model by using a continuous function to describe the rate 'constants' which forced the introduction of integration, rather than use several discrete values which led to simple calculations. He also asked what was the effect on grade of increasing the circulating load.

Dr Loveday replied that showing that the gamma function used to describe the rate constants required only two parameters, and that the integration necessary was not difficult to perform. He thought that more parameters would be introduced by the use of discrete values and that certain values could prove to be insensitive. In reply to the second part of the question, Dr Loveday indicated that the grade was maintained constant while the recovery was optimized. He added that alternative values of the grade could be selected.

Dr Reid congratulated the authors on their success in tackling a complete plant, a task which, in his opinion, had not been achieved previously. He added a plea that follow-up work should be undertaken immediately and asked what steps had been taken by Kennecott to achieve this and to verify the work done to date.

In replying Mr Weiss also added his congratulations to the authors and said that one of the benefits achieved to date was an excess of feed supply to the smelters resulting in a bottleneck where one had not existed previously. He said that the model was being used to provide the shift foremen with a visual display of operating parameters.

Dr Brook said that the use of discrete values of the rate constant as suggested by Kelsall was not suitable when changes occurred in the head grade, and asked what range of head grade variation the system could tolerate without the need to change the gamma function parameters.

Dr Loveday answered that the model was based on tests of the circulating load, and that the variations in the head grade did not occur due to the mining technique. Over a long period the head grade may show a slow drift in composition and minor alterations to the parameters would then be necessary.

Mr Moore asked if a situation had arisen where a further increase in the circulating load had led to a deterioration in the grade. Dr Loveday replied that this would occur when the cleaners were overloaded.

Dr R. P. King introduced his paper by outlining the philosophy behind the approach to flotation control that he had adopted, and the previous history that had led to this approach. He said that if a mathematical model was to be good it must be able to predict qualitatively the plant performance as a function of plant configuration, feed characteristics and operating conditions within the flotation cells, and must also be of use for design and scale-up, the determination of control strategy and the implementation of that strategy. The model could not be built at a desk but had to be conceived in the laboratory and on the pilot plant and should predict and mirror reality. As a result of these stringent requirements it was inevitable that mathematical complexity would be encountered if the mathematics were to describe the reality of the system accurately. He thought that the model should be based on each individual particle and that all the properties of each particle should be accounted for.

The test work necessary for the establishment of such a sophisticated model had been built and was currently being operated. This well-instrumented pilot plant was held under computer control and was thus capable of assessing all parameters as well as the predictive capabilities of the model.

Mr D. Watson said that as the gangue was explicitly excluded from the model, it was not capable of determining grade accurately. He added that the inclusion of the effects of gangue could alter the model substantially and quoted results obtained at Warren Springs which showed that the transfer of gangue material was much more susceptible to particle size than was the transfer of values, and concluded that models based on a distribution rate for the flotation of values may be very vulnerable.

Dr Whiten discussed the model being developed by his group. He said that the steady-state behaviour of the system was calculated by a simple iterative procedure following the process flow. The computational times were of a duration similar to those achieved by Dr King. Dr Whiten asked how it was planned to make the model match plant behaviour. Dr King replied that he hoped to model the pilot plant to plant configuration and use the pilot plant in conjunction with the industrial plant. This was an attempt to overcome difficulties which arise in large-tonnage plants, for example, inability to sample process streams accurately.

Mr Weiss commented that while the control of a flotation process was possible without a model, he doubted whether a process could be optimized without a model. He felt, however, that the system established at Kennecott was valid since they were searching for an improvement in plant performance and were not attempting to optimize their operation.

Mr Reid asked what effort would be necessary on behalf of a company if it wished to utilize the model to design a

flotation circuit. Dr King replied that the necessary parameters could be determined by inspection of the ore and by performing batch flotation tests.

In reply to questions concerning the effects of pH, the variation in ore types and a change in the per cent solids, Dr King said that the first two could be accommodated readily, but as the model was non-linear, he was uncertain as to whether it would be able to account for a change in the per cent solids.

In summing up, the Chairman, Dr R. E. Robinson, said that it was reasonable to say that control of crushing had reached a fairly advanced level as was revealed by Dr Whiten's paper. Regarding flotation control, the papers by Loveday and Marchant and by Amsden *et al*, had shown that a noteworthy advance had been made in the attempt to apply control to specific situations. This was particularly true at the Ecstall Mine where management had participated actively and where exceptional financial gains had been obtained. Dr King's paper described an attempt to develop a comprehensive model to describe flotation by taking into account all factors which affect flotation. His was acknowledged as a very long-term undertaking but one that was essential, in order that flotation could be fully understood and plant operating characteristics correctly interpreted.

All papers had shown the good advantage to which computers could be put in the metallurgical processing field and in time they could be considered an essential and integral part of the strategy necessary to exploit an ore body.