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Computer aided design and optimization of mineral processing plants by a state of the art simulator

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ABSTRACT

Tata Research Development and Design Centre (TRDDC) has developed a state of the art mineral processing simulator called SimL8. It performs modelling, simulation and optimisation functions and provides viable strategies for enhancement of the performance of mineral processing plants. A number of case studies on plant diagnostics, grinding, classification, flotation and pressure filtration are taken up to demonstrate the utility of modelling and simulation on SimL8 platform.

***Keywords** : Modeling, Simulation, Plant audit, Diagnostics, Data reconciliation, SimL8, Grinding, Classification, Flotation, Circuit design, Filtration.*

INTRODUCTION

The efficiency and viability of a mineral processing plant operation is determined by its productivity, yield, product quality, cost, energy consumption, environmental impact and so on. These indices, in turn, are impacted by the chemistry of the process, as controlled by chemicals, reagents, surfactants, polymers, pH etc., and by the physical unit operations employed. The advances made in molecular structure, properties and behaviour now permit us to select chemicals with much greater reliance on our understanding of the fundamentals than on empirical knowledge. Molecular modeling and reagent design is an emerging field, which holds considerable promise for mineral processing industry. Recent advances in reagent design[1-14] have shown that it is possible to identify more selective reagents, tailor - made for a specific separation problem at hand. Detailed discussion on these topics, however, is outside the purview of this paper. The reader is referred to several excellent monograph and reviews.

Improvement in the process chemistry, in isolation, is by no means adequate for optimisation of the mineral processing plant. It is concurrently necessary to analyse in detail the various unit operations that comprise the plant as well as the manner in which these are interconnected, that is, the circuit configuration. For this purpose, one has to carry out computer aided process design, simulation, optimisation and circuit synthesis. SimL8, the state of the art mineral processing simulator developed by TRDDC, perform these tasks with relative ease in a user friendly environment.

As shown in Fig.1, the first step in an exercise directed at plant optimisation usually calls for collection of plant data, followed by data reconciliation, plant audit and diagnostics. Next step entails acquiring or building mathematical models of the various unit operations comprising the plant, such as size reduction, classification, beneficiation, liquid-solid separation etc. The models can be empirical, semi-empirical or more realistic and detailed phenomenological models in the particle population balance paradigm. The last approach requires a sound understanding of the actual physical phenomena prevailing in a unit operation. Once the mathematical models are validated with plant / laboratory data, it should be possible to simulate the performance of individual units and the circuit as a whole, and come up with strategies for performance enhancement. These complex and computational intensive tasks are best carried out with help of a tailor-made, dedicated and user-friendly modeling-simulation tool such as SimL8.

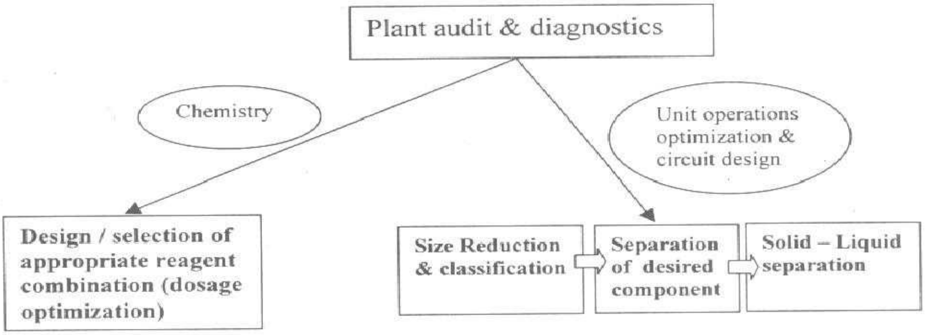

Fig. 1 : Schematic diagram showing various steps in plant optimization

MODELING-SIMULATION TOOLS

Very few commercial modelling-simulation tools for mineral processing plants are currently available. These are USIM PAC from BRGM, France; JKSimFloat from JKMRC, Australia; and SimL8 from TRDDC, Pune. Based on more than fifteen years of TRDDC experience in modelling, simulation and optimization of mineral processing unit operations and circuits, SimL8 was developed in collaboration with the software-engineering group of Tata Consultancy Services and Hindustan Zinc Limited. It incorporates the latest Simulator Development Environment (SDE), a proprietary technology of Tata Consultancy Services, which enables seamless additions of new unit operations, process models, solvers or optimisers. SimL8 has 3 modes of operation, namely, data reconciliation[16,17], parameter estimation and simulation. It has a user friendly graphical user interface, which interacts with the backend solver, optimiser and a large backend library of process models. The architecture of SimL8 is shown in Fig 2.

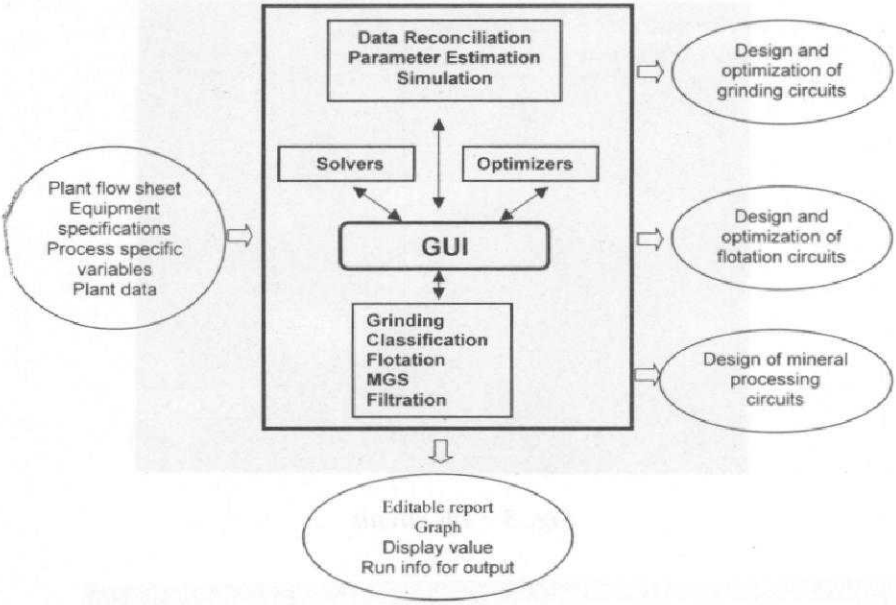

Fig. 2 : Architecture of SimL8

CASE STUDIES

A few case studies carried out by us are presented in the following sections to illustrate the utility and power of SimL8.

Plant Audit and Diagnostics[15-17]

A process audit is a methodical and systematical exploration of a system for quantifying its performance. Process auditing of a mineral processing plant at regular intervals can provide valuable information to the plant engineers regarding the plant health and drift in the plant performance with time. It is also possible to identify the problematic process units from the plant audit. This case study was done on a Pb circuit, shown in Fig. 3, of a Pb-Zn plant. The Pb circuit comprises of rougher (Ro), scavenger (Sc), cleaner1 (Cl1), cleaner2 (Cl2) and cleaner3 (Cl3) banks.

Based on reconciled data, the bar-charts in Figure 4 show the variation in the Pb grade and Pb recovery across various runs.

Amounts of graphite carbon and insoluble across the runs are shown in Fig. 5.

The variations in the performance of different process units across the data sets are shown in Fig. 6(a-d). In an ideal separation the distribution of the desired component (Pb) is unity and undesirables (Gr. C, Insoluble) zero.

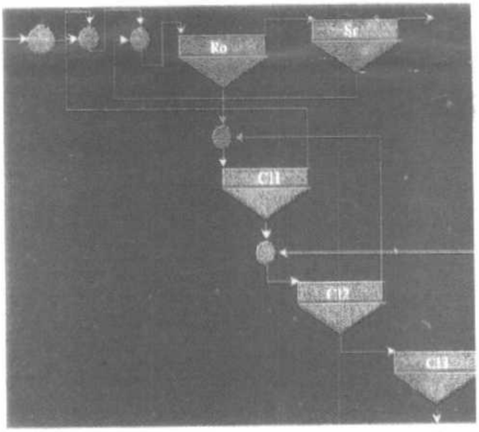

Fig. 3 : Pb circuit

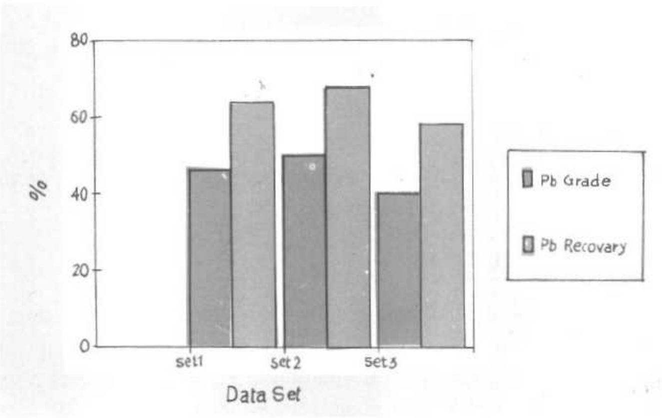

Fig. 4 : Pb grade and recovery across various runs

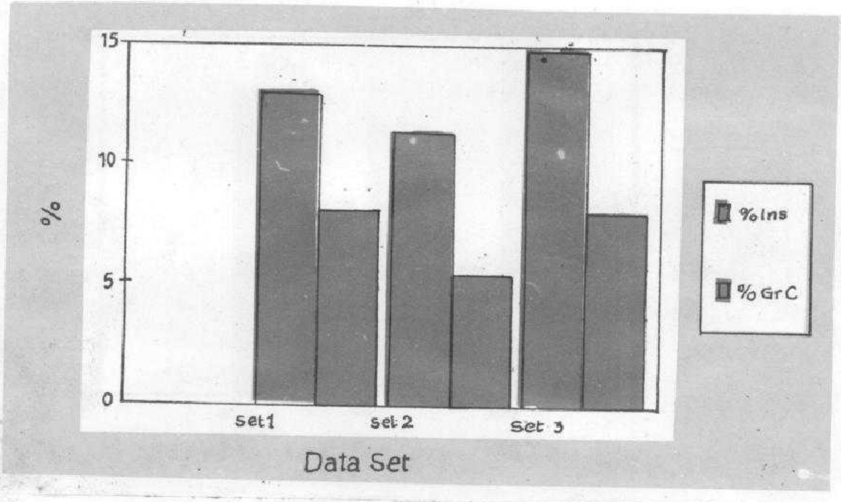

Fig. 5 : Impurities in Pb concentrate

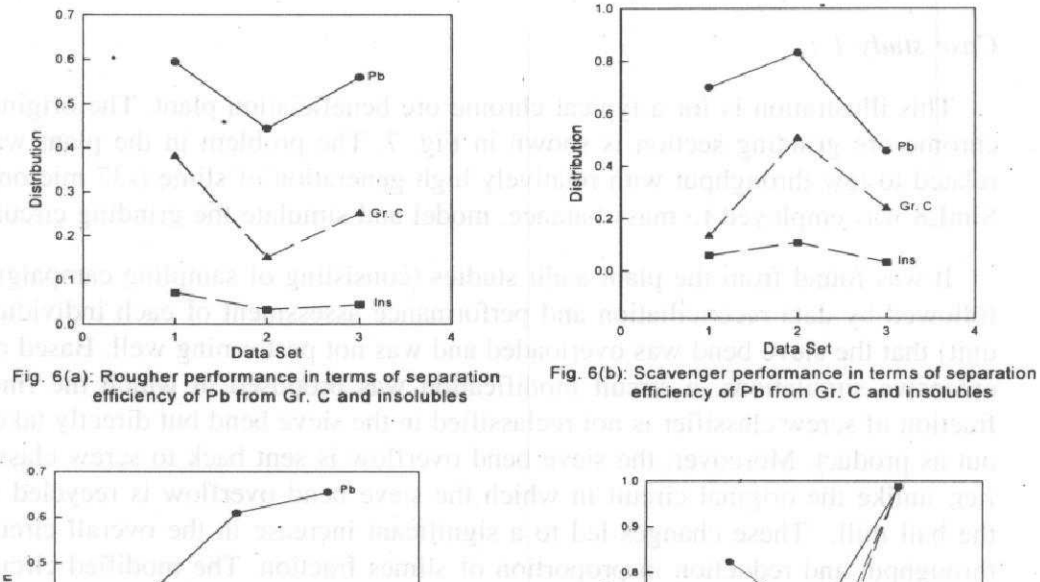

Fig. 6(a): Rougher performance in terms of separation efficiency of Pb from Gr. C and insolubles

Fig. 6(b): Scavenger performance in terms of separation efficiency of Pb from Gr. C and insolubles

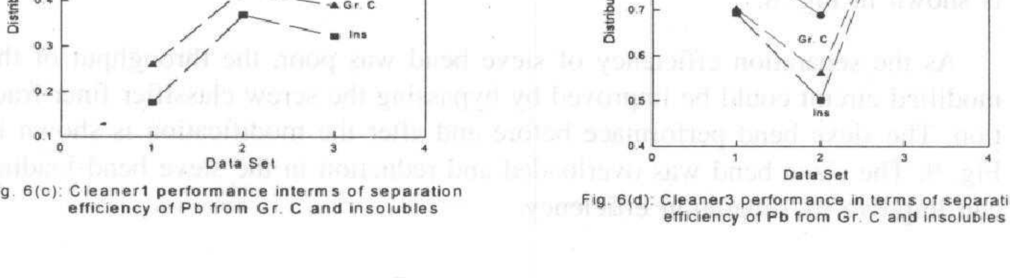

Fig. 6(c): Cleaner1 performance interms of separation efficiency of Pb from Gr. C and insolubles

Fig. 6(d): Cleaner3 performance in terms of separation efficiency of Pb from Gr. C and insolubles

Figure 6 (a, b, c, d)

It will be seen from these plots that there are considerable variations in the performance of the process units in different runs. On the whole, Rougher and Scavenger are working reasonably efficiently as compared to the cleaner banks in rejecting insolubles. For separating Pb, Cleaner1 is not working well; however, cleaner 3 has better separation performance for Pb , and in set 3 it is performing quite well.

Information of this kind based on plant data but appropriately reconciled for mass balances using a tool like SimL8, if collected on a regular basis and documented, again with the help of a data processing tool like SimL8 having those functionalities, can provide valuable means of optimizing plant performance. If the trends of this kind established on the basis of plant data are correlated with actual mineralogical or operating conditions, one can make suitable changes to enhance plant performance.

Grinding and Classification[18-28]

Case study 1 :

This illustration is for a typical chrome ore beneficiation plant. The original chrome ore grinding section is shown in Fig. 7. The problem in the plant was related to low throughput with relatively high generation of slime (-37 micron). SimL8 was employed to mass balance, model and simulate the grinding circuit.

It was found from the plant audit studies (consisting of sampling campaigns followed by data reconciliation and performance assessment of each individual unit) that the sieve bend was overloaded and was not performing well. Based on extensive simulations, a circuit modification was proposed in which the finer fraction of screw classifier is not reclassified in the sieve bend but directly taken out as product. Moreover, the sieve bend overflow is sent back to screw classifier, unlike the original circuit in which the sieve bend overflow is recycled to the ball mill. These changes led to a significant increase in the overall circuit throughput and reduction in proportion of slimes fraction. The modified circuit is shown in Fig. 8.

As the separation efficiency of sieve bend was poor, the throughput of the modified circuit could be improved by bypassing the screw classifier finer fraction. The sieve bend performace before and after the modification is shown in Fig. 9. The sieve bend was overloaded and reduction in the sieve bend loading can improve its separation efficiency.

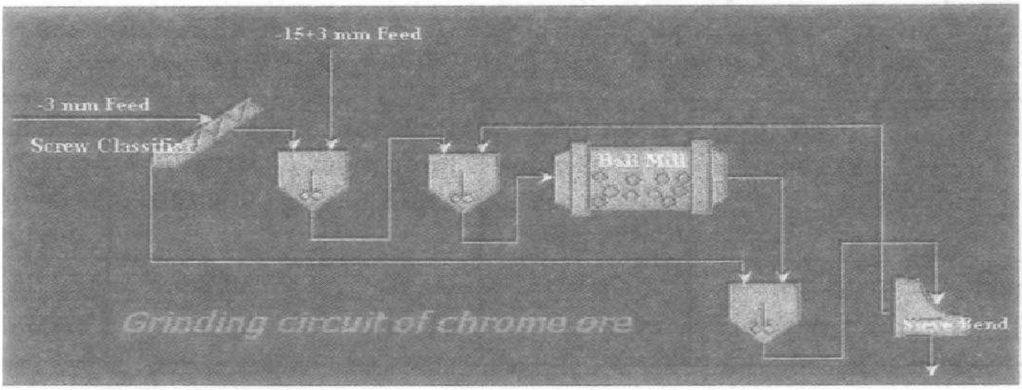

Fig. 7 : Chrome ore grinding circuit

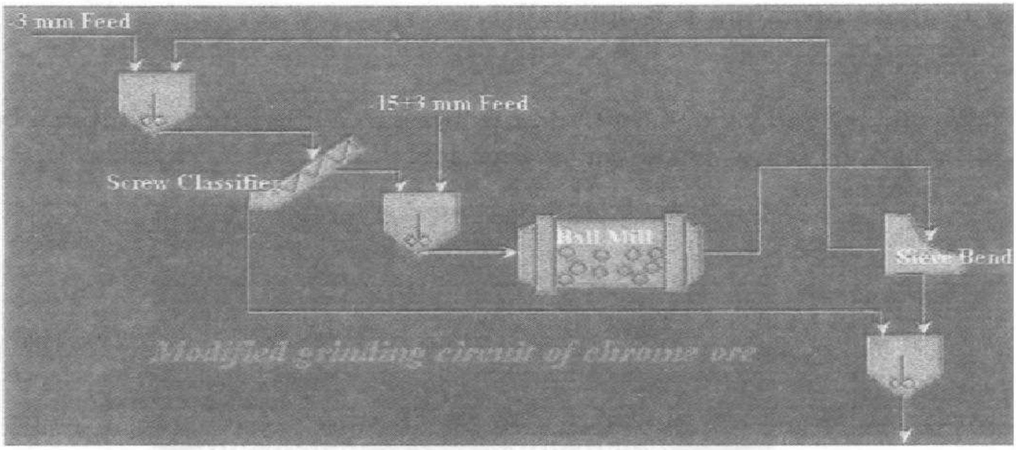

Fig. 8 : Modified chrome ore grinding circuit

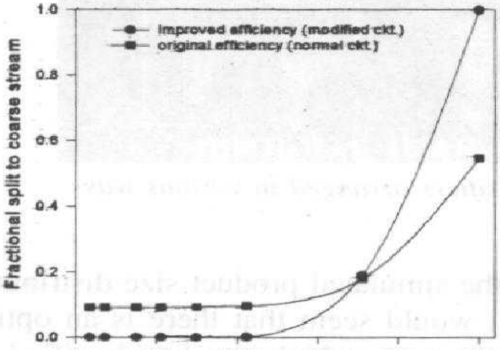

Fig. 9 : Sieve bend efficiency

A comparison of the performance of the two circuits is shown in Table 1.

Table 1 : Comparison of performance of two circuits

Circuit	Feed (t/hr) (-3 mm)	Feed (t/hr) (-15+3 mm)	Ball mill throughput (t/hr)	Product. wt% (-37 micron)	Product wt% (-500+37 micron)
Normal	81.46	25.70	69.70	34.88	62.95
Modified ckt	151.39	47.76	112.18	34.13	65.45

A tool like SimL8 can thus be very gainfully utilised in plant practice in not only assessing the unit performance quantitatively but also to find suitable remedies to those operating sub-optimally.

Case study 2

The primary and secondary hydrocyclones in a classifier circuit can be combined in various ways as shown in Fig. 10.

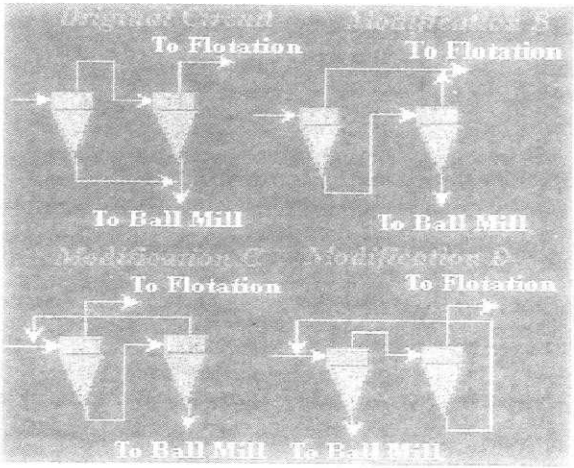

Fig. 10 : Classifiers arranged in various ways

The plots in Fig. 11 shows the simulated product size distributions obtained under different modifications. It would seem that there is an optimal classifier circuit for a given product requirement, which can be identified by modelling and simulation.

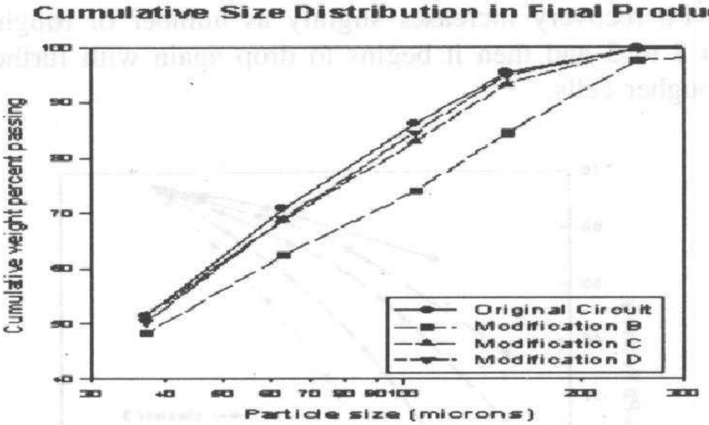

Fig. 11 : Product size distribution in various hydrocyclone arrangements

Flotation circuit[29-33]

The flotation circuit will be described with a case study of the Pb circuit already shown in Fig. 3.

Case study 1 :

Some interesting simulation results were obtained when the final Pb concentrate stream is fed back to various banks i.e., rougher, scavenger, cleaner1, cleaner2 and cleaner 3. Fig. 12 illustrates the effect of recycling path (the results of increasing proportion of recycling of final concentrate back to the flotation circuit) on the rejection of graphite carbon content and Pb recovery. It would seem that recycling of final concentrate to scavenger has the most disastrous effect on lead recovery with only a small improvement in graphite carbon rejection. This is expected since material fed to scavenger bank will go out of final tails, leading to high loss of valuable material. When recycled to rougher bank, even though the recovery drops, it is accompanied with a better performance in graphite rejection. Recycling in cleaner 1, cleaner 2 and cleaner 3 shows improved performance with better rejection of graphite carbon and lower drop in recovery in that order. The simulation results suggest that cleaner 3 concentrate can be recycled back for improving the quality of concentrate.

Case study 2 :

Based on empirical experience, plant engineers often shift cells from one bank to another. The effect of shifting some cells from rougher to scavenger bank was simulated with SimL8. Fig. 13 shows the effect of increasing the number of rougher cells, while keeping total number of rougher and scavenger cells constant, on Pb grade and recovery. With an increase in number of rougher cells, Pb grade drops. Pb recovery increases slightly as number of rougher cell is increased from 2 to 3 and then it begins to drop again with further increase in number of rougher cells.

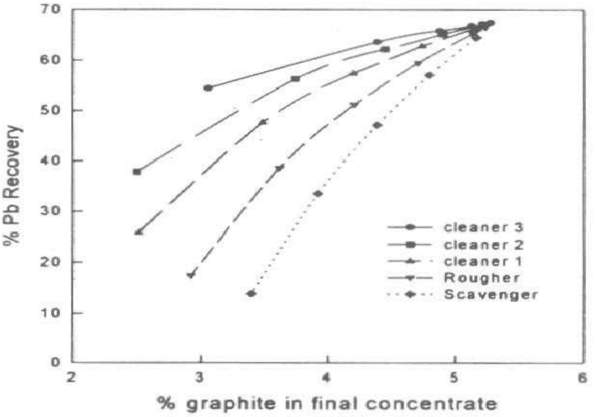

Fig. 12 : Effect of recycling of final concentrate at various banks

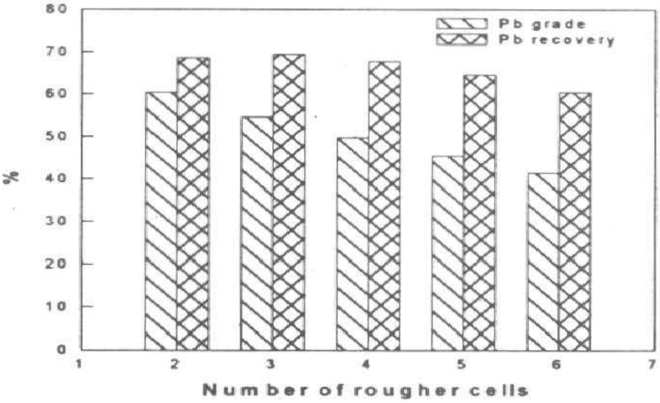

Fig. 13 : Cells from acavenger to rougher

0-th level simulation :

SimL8 has many detailed and realistic mathematical models for grinding, classification and flotation. For other unit operations, which have not been modelled yet, a facility of 0-th level simulation has been provided. In 0-th level simulation, it is assumed that separation efficiency of a process unit, which can be calculated in SimL8, remains approximately invariant of any reasonable modification in the circuit configuration. Thus, one set of separation efficiencies can be employed to simulate the modified circuits. This is demonstrated with reference to the Pb circuit in Fig. 3. It is known that a multi gravity separator (MGS) can be quite effective in rejecting graphite carbon from the Pb circuit. A decision had to be taken regarding the position of MGS in the Pb circuit. With this objective in mind, several circuit configurations were tested by simulation in order to obtain the best possible circuit configuration. Fig. 14 shows the optimal circuit configuration obtained. There is a significant improvement in Pb grade with only marginal drop in recovery when MGS feed comes from cleaner 1 concentrate and cleaner 2 tails. Table 2 shows the expected performance of different circuit modification.

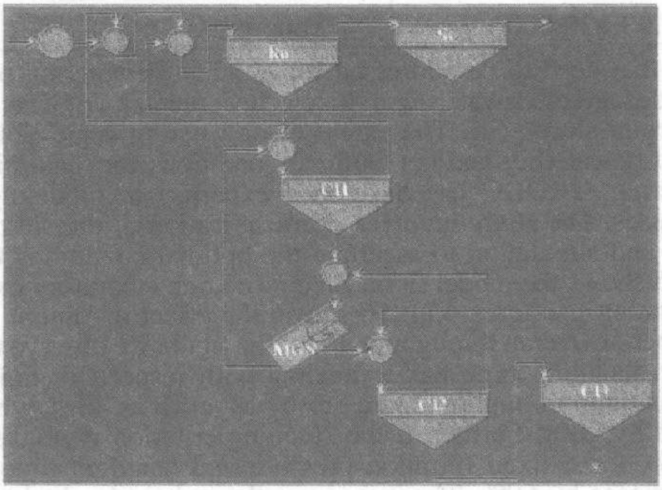

Fig. 14 : Pb circuit with MGS

Table 2 : Effect of MGS on Performance of Pb Circuit

Circuit Configuration				Grade (%)		Recovery (%)
				Pb	Gr.C	Pb
Without MGS				48.12	9.58	62.26
With MGS	Feed	Conc.	Tail			
	Scavenger Conc	Cleaner 1	Rougher	46.17	8.74	66.67
	Cleaner 1 Conc	Cleaner 2	Cleaner 1	71.87	0.86	50.88
	Rougher Conc	Cleaner 1	Rougher	71.23	0.81	46.29
	Cleaner 1 Conc and Cleaner 2 tail	Cleaner 2	Cleaner 1	**68.41**	**0.75**	**57.19**
	Cleaner 1 Conc	Cleaner 2	Rougher	73.15	0.67	41.66

Solid Liquid Separation[34-36]

All mineral processing plants have solid liquid separation units, like thickener, pressure filtration etc. The various solid liquid separation devices are listed in Table 3.

Table 3 : Dewatering devices

Pressure (kPa)	Device
0	Gravity belt filter
<10	Thickener
<200	Vacuum and drum filter
<500	Ceramic drum filter
200-1,000	Belt press filter
1,000-3,000	Plate and frame filter
5,000-20,000	Tube press

The issues that need to be addressed for efficient dewatering operation are: (i) The optimum dosage of dewatering aids (eg. flocculants), (ii) The best dewatering aid for a particular slurry, (iii) The extent of dewatering achievable economically, (iv) The rate of dewatering and (v) Optimal conditions for maximizing extent and rate of dewatering. TRDDC has developed expertise in modeling simulation of filtration processes. The study involves characterisation of the slurry in the laboratory, modeling and simulation to ascertain the optimal conditions for the filtration process. Fig. 15 shows the model fit on Zn concentrate laboratory experimental data at various operating pressures. Fig. 16 shows the effect of initial slurry height in filtration chamber on overall throughput. From the figure we observe that the throughput for a given handling time has a maxima with respect to initial slurry filling height. The maximum throughput increases by as much as 40 % when the handling time is reduced by 200s. Further, if the stopping criterion is relaxed from a value of 16% to 10%, for a fixed filtration pressure and handling time, the maximum throughput increases by 50%. The maximum throughput is obtained when the filtration time is same as the handling time.

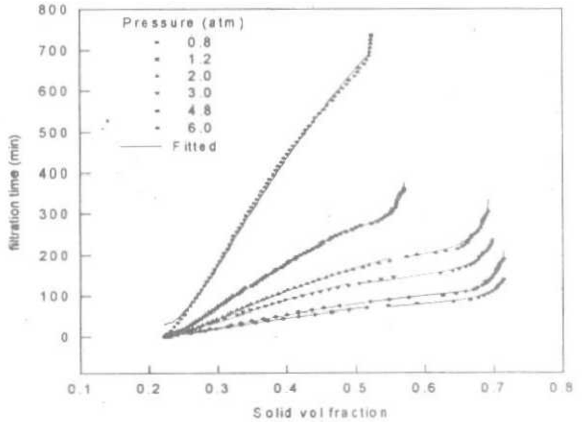

Fig. 15 : Comparison of experimental data and model prediction of Zn conc.

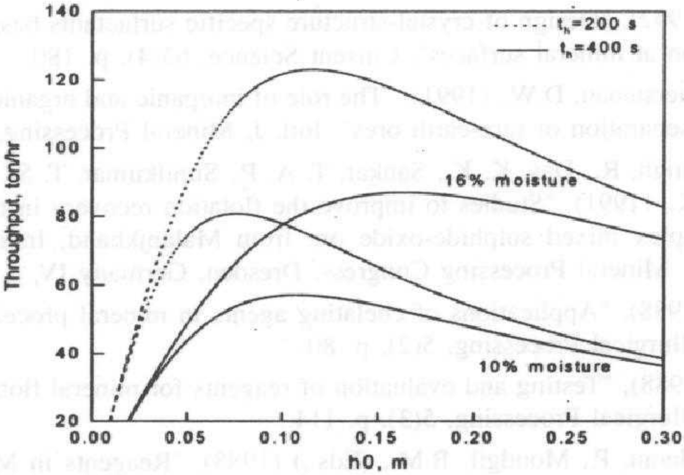

Fig. 16 : Effect of initial slurry height on overall throughput

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