Computer control of flotation at the Ecstall concentrator[$]

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SYNOPSIS

Ecstall Mining Limited, a subsidiary of Texas Gulf Sulphur Company, operates the Kidd Creek Mine, a 10 000 tons per day base metal producer, near Timmins, Ontario. Two different types of ore are mined and milled: copper-zinc and silver-lead-zinc. At the highly automated Ecstall concentrator the ores are processed by selective flotation in three individual circuits. One of the most important metallurgical tools for process control is a sample system incorporating continuous on-stream X-ray analysis. Recently this system was automated further by the addition of computer control of reagents for two copper-zinc flotation circuits. The computer programs, utilizing optimum seeking methods and smelter contract terms, have increased copper recovery by 1,1 per cent, zinc recovery by 1,4 per cent, and have reduced reagent costs by 16 per cent. Although not expected, copper and zinc concentrate grades were improved slightly as well.

SINOPSIS

Ecstall Mining Limited, 'n dogtermaatskappy van Texas Gulf Sulphur Company, werk die Kidd Creek Myn naby Timmins, Ontario wat 'n 10 000 ton per dag onedele metaal produseerder is. Twee verskillende tipes erts word gemyn, nl., koper-sink en silver-lood-sink. In die hoogs geoutomatieseerde Ecstall aanleg word die erts behandel deur selektiewe flotasie in drie verskillende kringlope. Een van die mees belangrike metallurgiese metodes vir proses kontrole is 'n monster sisteem waarby in lyn X-strale analise ingesluit is. Onlangs is die sisteem verder geoutomatiseer deur die byvoeging van komper kontrole van reagense vir twee koper-sink flotasie kringlope. Die komper programme, wat gebruik maak van die soek van bes moontlik metodes en smelter kontrak terme, het koper herwinning by 1,1 persent en sink herwinning by 1,4 persent opgestoot en het reagens koste met 16 persent gesnoei. Alhoewel dit nie verwag was nie is die graad van koper en sink konsentrate ook ietwat verbeter.

INTRODUCTION

Ecstall Mining Limited, a wholly-owned subsidiary of the Texas Gulf Sulphur Company, operates the Kidd Creek Mine, one of the world's major base metal producers, near the old gold mining centre of Timmins, Ontario. Discovered in 1964, the property was brought into production in November, 1966. Originally designed for 9 000 tons per day, the operation now treats 10 000 tons per day of two different types of ore mined from a single open pit. In the near future, open pit ore will be supplemented by ore from an underground operation now being prepared for production.

At the Ecstall concentrator the ores are processed by selective flotation in three individual circuits. The whole plant is highly automated and control is coordinated from a central control room. The treatment process follows conventional practices although fine grinding is required for optimum flotation recoveries. Normally, two circuits treat copper-zinc ore at a combined rate of 6 500 tons per day while the third circuit treats 3 500 tons per day of silver-lead-zinc ore. Special attention is paid to grade control to maintain steady heads for both ore types. Four concentrates are produced: copper, lead, low silver-zinc and high silver-zinc concentrates. Daily concentrate production averages 2 400 tons per day.

One of the most important metallurgical tools for process control is a sample system incorporating continuous on-stream X-ray analysis and pH control. As a high level of metallurgical efficiency had been achieved by means of this system and by manual control of reagents, it was decided recently to go one step further and to use a computer for direct digital control of flotation metallurgy. The basic approach to computer control has been to "keep it simple". So far, computer control has been in operation on the two copper-zinc circuits for only a short period but it has already reduced costs and improved metallurgical results appreciably. The evolution and implementation of computer controls are described in this paper.

GENERAL DESCRIPTION OF OPERATIONS

Crushing

The mine and concentrator are located 17 miles apart. Ore is crushed to minus 6 in. at the mine and then delivered by rail to the concentrator where it is reduced in two stages to minus $\frac{5}{8}$ in. The fine-crushing plant at the concentrator is designed to handle 800 tons per hour. Separate crushing of both ore types must be scheduled carefully to keep fine ore bin inventories at good working levels.

Grinding

Each of the three parallel grinding circuits consists of a rod mill followed by a primary ball mill in closed circuit with cyclones. For copper-zinc ore, cyclone overflow at 55 per cent minus 325 mesh and 51 per cent solids is aerated and treated by a primary flotation step to recover coarse liberated chalcopyrite. Primary copper tails are ground further in a secondary ball mill circuit

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to 80 per cent minus 325 mesh and secondary copper flotation and zinc flotation are completed. In the treatment of silver-lead-zinc ore, flotation is not carried out until the final grind of 75 per cent minus 325 mesh is achieved because of the absence of coarse galena mineralization. Regrind ball mills are provided for the retreatment of copper and zinc middlings.

Flotation

Copper, lead and zinc roughing and scavenging is carried out in No. 66 Wemco Fagergren machines. Zinc and lead cleaning is also done in No. 66 Wemco machines but copper cleaning is done in No. 24 Sub A Denver Cells. Copper and zinc concentrates are cleaned three times in an open circuit configuration. Silver-lead cleaning is countercurrent to optimize silver recovery.

In copper flotation, pulp pH is controlled at 6,7 with lime and sulphur dioxide to depress sphalerite and pyrite. Reagent 208 (a sodium dithiophosphate) the major copper collector, is metered to the primary conditioner, secondary conditioner and secondary scavenger feed. Reagent 317 (sodium isobutyl xanthate) is also added to the secondary scavenger feed to float copper middlings. MIBC (methyl isobutyl carbinol), the frother used, is added to the primary conditioner. Sodium cyanide is used in copper cleaning for additional pyrite depression.

Zinc flotation requires sphalerite activation by copper sulphate and is carried out in a lime medium at pH 11. Reagent 317 is used as a rougher and scavenger collector with minor amounts of Dowfroth 250 (polypropylene glycol methyl ether) used as a frother.

Lead-silver flotation is conducted in a soda ash medium at pH 8,6. Reagent 208 and Reagent 317 are used to recover the silver-lead values.

Dewatering

Copper, silver-lead, and zinc concentrates are thickened to 65 per cent solids, filtered and dried in Nichols Herreshoff Multiple-Hearth dryers to 6 per cent moisture.

Reagent handling

All reagents (except sodium cyanide) are received in bulk quantities. Automated mixing reduces errors and provides constant solution strengths, an important factor in the smooth operation of the flotation circuits.

Reagents are circulated from holding tanks to constant-head tanks. From the head tanks they are directed to the flotation circuits by rotameters. The rotameters for each circuit are mounted on an individual panel located in the central control complex.

Process control

The operation is controlled closely in all sections of the concentrator. Most of the crushing, grinding and flotation equipment is started from individual operating panels in central control. Crushing is monitored by closed-circuit television and nuclear gauges are used to indicate bin and chute levels. Set-point control is used to regulate rod mill feed rates. Cyclone overflow pulp densities are controlled by nuclear gauges. Flotation pulp levels are regulated automatically. Assays of flotation products are provided by two ARL on-stream X-ray analysers and a Honeywell model H-21 computer. The H-21 computer also monitors mill bearing temperatures and provides logs of shift and daily tons crushed, milled and concentrate loaded out. The application of process control to the flotation circuits is illustrated in Fig. 1.

Of prime importance to flotation control is the sampling system incorporating the on-stream X-ray analysers and the H-21 computer. The process streams to be sampled pass through conditioners equipped with powerful Lightnin mixers. Vertical pumps mounted on top of the tanks deliver approximately 50 gallons per minute of slurry to small constant-head tanks located in a sample room above the X-ray analysers. The head tanks overflow through Denver samplers which take cuts every 20 minutes. These cuts are filtered continuously and collected every 24 hours for chemical assay. Where required, pH is sensed by electrodes immersed in the head tanks. Approximately four gallons per minute flow to the X-ray analyser.

Assay data are generated by the H-21 computer from X-ray voltage readings and presented on IBM No. 11C logging typewriters at the central control operator's desk. Copper, lead, zinc, silver and iron assays are available on 15 process streams. For each of three flotation circuits, heads, copper-lead concentrates and tailings, and zinc concentrates and tailings are analysed. A complete set of assays, ratio of concentrations and recoveries is presented every 12 min for the two copper-zinc circuits and once every 6 min for the silver-lead-zinc circuit. The computer also provides shift and daily averages of these data. Assay type-out availability exceeds 95 per cent.

DEVELOPMENT OF COMPUTER CONTROL

Motivation

After the plant had been operating for two years it was believed that metallurgical efficiencies could be improved further. Computer control would overcome natural human limitations in continuous process monitoring and rapid, accurate operating decision making. It was estimated that a more efficient correlation of X-ray assay data and reagent additions would improve metal recoveries by 0,5 per cent and reduce reagent costs by 10 per cent. These improvements represented an expected gross saving of $735 000 per year.

System definition

Selection of the level of automatic control to be executed followed an analysis of the measured assays and reagents manipulated within the existing framework used for manual control. Those X-ray data selected for automatic control input and their average deviations from standard chemical analysis are shown in Table I.

The reagents most often manipulated in the manual control of the three flotation circuits were selected for automatic control. They were: Reagent 208 at three points and Reagent 317 at one point in each copper circuit; Reagent 317 and copper sulphate at one point in each zinc circuit; Reagent 208 and Reagent 317

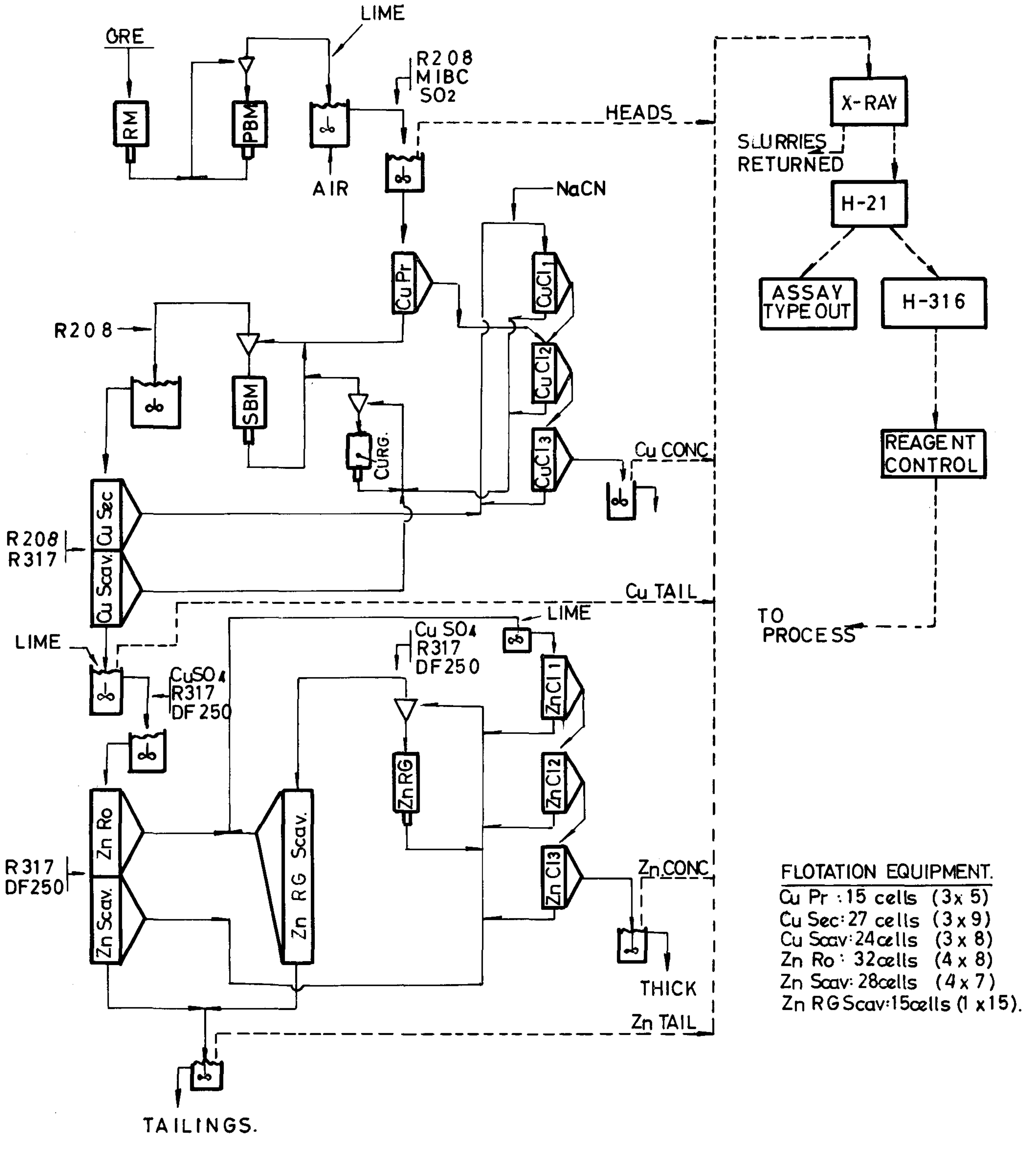


Fig. 1—Process flowsheet.

TABLE I

Copper-zinc ore	% Copper	% Zinc
Head	2,0 ± 0,14	8,50 ± 0,42
Copper concentrate	24,00 ± 0,60	6,00 ± 0,42
Copper tailing	0,10 ± 0,01	9,00 ± 0,45
Zinc concentrate		54,50 ± 1,09
Zinc tailing		0,45 ± 0,04
Silver-lead-zinc ore		
Head	1,00 ± 0,07	11,50 ± 0,90
Lead concentrate	13,00 ± 0,42	11,00 ± 0,50
Lead tailing	0,40 ± 0,04	11,50 ± 0,90
Zinc concentrate		51,00 ± 1,02
Zinc tailing		1,50 ± 0,15

at two points in the lead circuit. After the key X-ray assay data and reagent flows had been defined, digital control was selected as the most efficient link between these measured and manipulated process variables.

Equipment selection and installation

Equipment was selected to permit the automatic system to be incorporated in parallel with, rather than in place of, existing manual control facilities. The computer chosen for this purpose was a Honeywell, model H-316, digital computer (16-bit word length and 1,6 micro-second memory cycle time) with 4 096-word magnetic core memory module, real-time interface providing 64 digital inputs and 40 digital outputs, real-time clock and A.S.R. No. 33 input/output teletype. Selected for automatic reagent control were 18 control loops each consisting of a logic interface control unit, a synchronous A.C. motor-driven precision pressure regulator, and a Worthington pneumatic control valve activated by a positioning cylinder. Provision for alternating between automatic and manual control was easily included. In addition, the system was designed to permit manual overrides for each reagent flow while retaining the computer control strategy.

The H-316 computer would obtain assay data from the H-21 computer, ascertain their validity, analyse them to determine the need for reagent changes, select the appropriate reagent flows, and administer the necessary adjustments. This sequence was to be executed according to the availability of assay data.

All computer programming was done by Ecstall metallurgical staff, in consultation with Honeywell programmers. Installation, check-out, and calibration of equipment were supervised by Ecstall instrumentation staff. The total cost of the project was estimated to be $100 000. Responsibility for the system was assigned to an engineer assisted by one technician.

Original control strategy

A flow diagram of the reagent control strategy attempted initially is illustrated in Fig. 2. This control strategy paralleled manual operating practice followed at the time. Metallurgical target set points to correspond with the flotation properties of the various ore blends treated were entered through the ASR teletype. Maximum/minimum set points were selected by adjusting microswitch contact closures measuring Worthington control valve stem travel. Increasing/decreasing step sizes were selected by adjusting the time constants on the A.C. motor drives.

During the first months of on-stream testing, a number of major difficulties arose. A thorough tuning of maximum/minimum flow limits and increasing/decreasing step sizes was required to achieve a correct proportioning of reagent flows adjusted sequentially by the computerized strategy. In fact, manipulation of these set points was found to play a key role in modifying the control strategy to suit varying flotation conditions. Variations in ore characteristics and mechanical operating conditions occurred with sufficient frequency to prevent accurate metallurgical targets to be programmed manually. The targets were either unattainable or under-estimated.

The automatic control of zinc flotation reagents presented more specific problems. An overall calculated zinc recovery (including compensation for zinc recovered in copper concentrates) was not sufficiently accurate to allow precise control of zinc flotation circuit metallurgy. Feed-back control of copper sulphate was too upsetting to zinc circuit stability. Automatic control of Reagent 317 and copper sulphate additions to zinc middlings retreatment (not included in the original control strategy) was essential to achieve optimum zinc metallurgy.

To resolve these inadequacies effectively, and to ensure a continuing improvement of the reagent controlling strategies, a program of control studies was initiated with priorities to improve metallurgy in (i) the copper circuits, (ii) the zinc circuits and (iii) the lead circuit.

Development of copper control strategy

Testing of the original control strategy verified the technique for sequentially proportioning collector additions. After a significant revision, the set points selected for step sizes proved valid for all operating conditions. However, flow limits required frequent adjustment, particularly at the scavenging stage, to suit the flotation characteristics of various ore blends.

Considerable effort has been expended in optimizing the computerized technique for determining, from X-ray assay data, the need and direction for collector adjustments. To allow the computer complete flexibility in striving for an optimum metallurgical balance, the control strategy was modified to include a matrix of copper grades and recoveries replacing the original target set points. This matrix was developed from a study of smelter contract economics and a knowledge of the operating limitations of the copper flotation circuits. The computer was programmed to call at each half per cent increment of grade and one per cent increment of recovery for either an increase or a decrease in the copper collector addition. In utilizing the grade/recovery matrix to search continuously for an improved metallurgical balance, the computer would not permit collector addition levels to remain constant. As a result, some short-period cycling of metallurgical performance was inevitable. However, the cycle average approximated closely optimum economics as defined by the grade/recovery matrix. This strategy also provided a positive

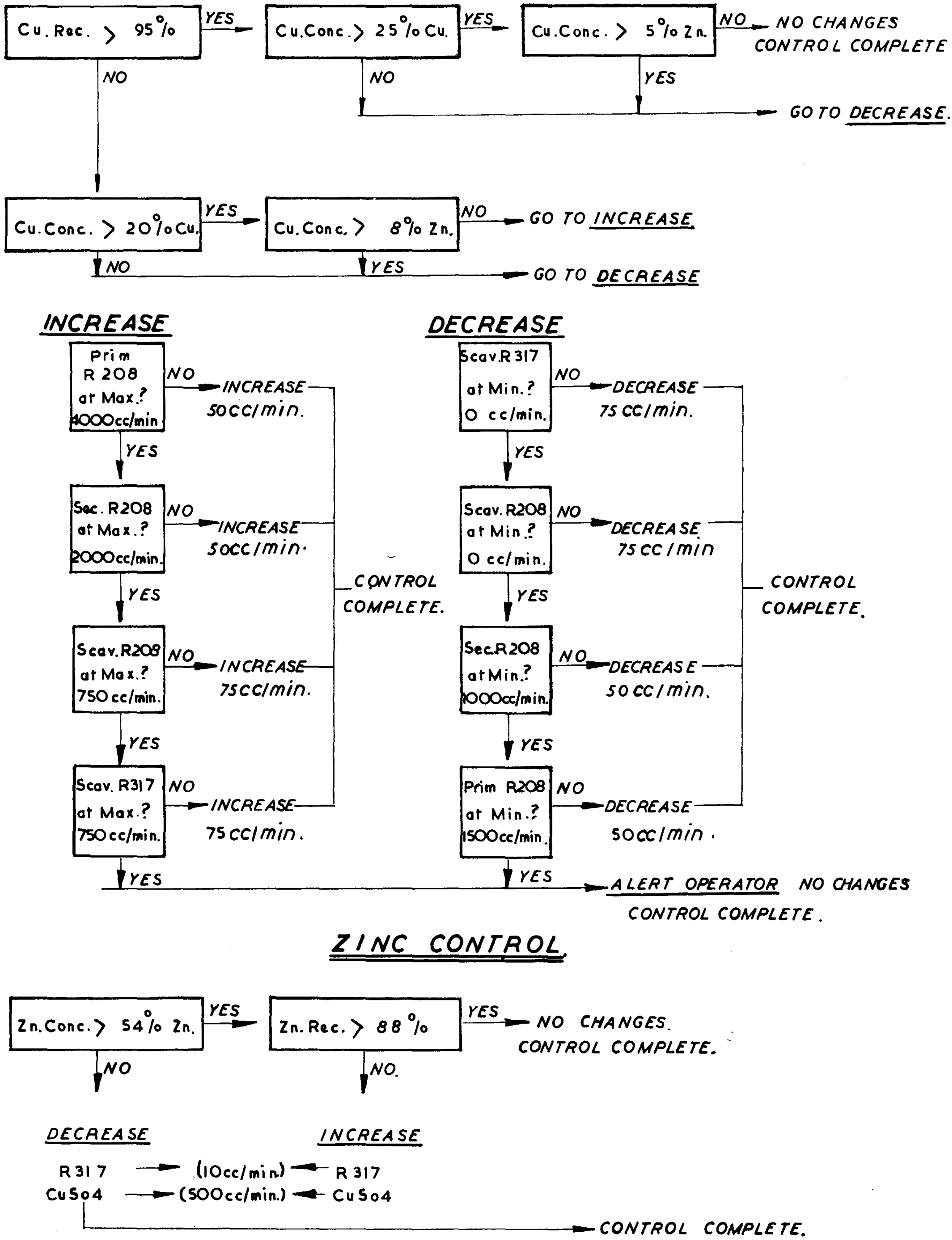
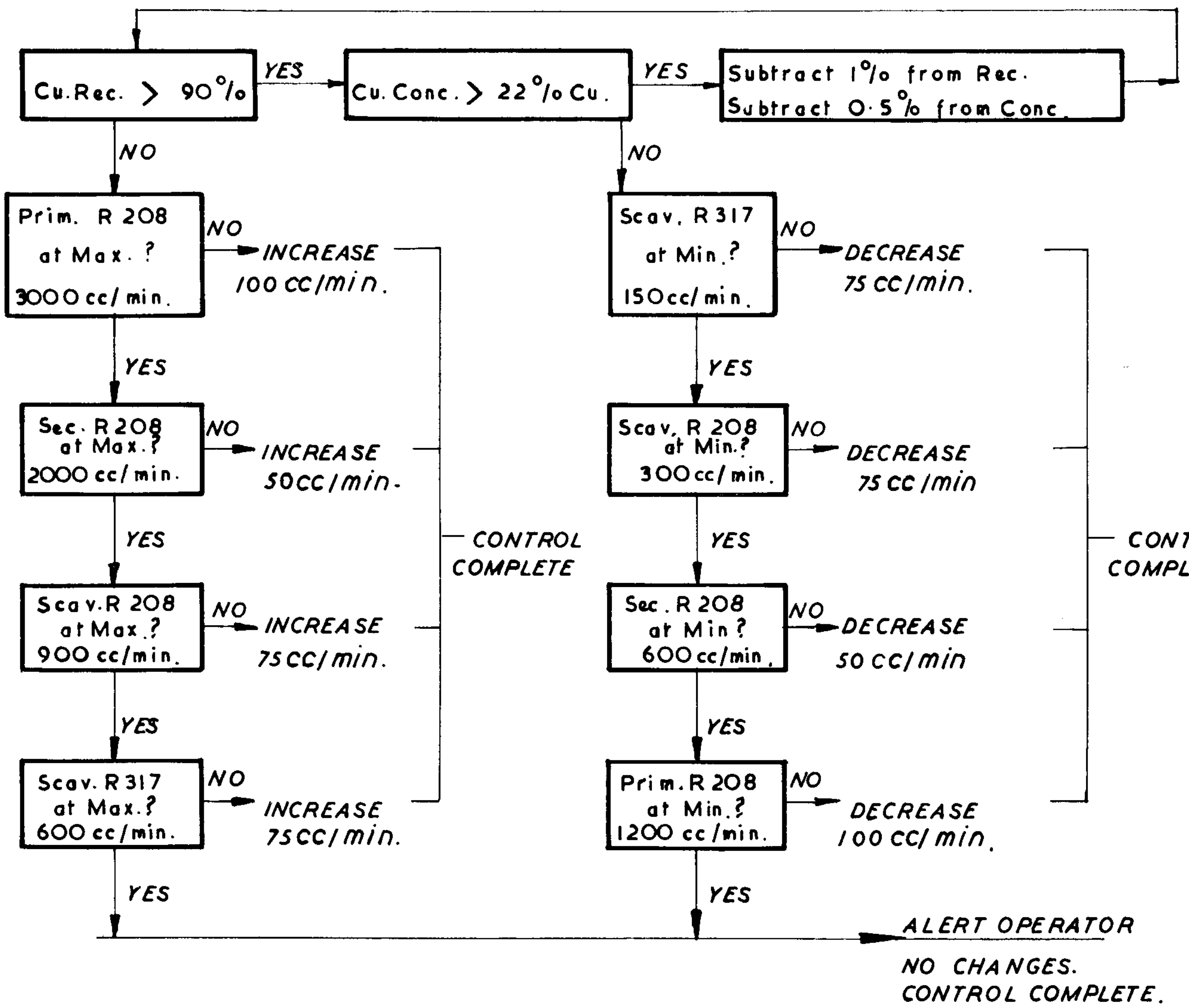


Fig. 2—Original strategy for copper control.



GRADE / RECOVERY MATRIX.

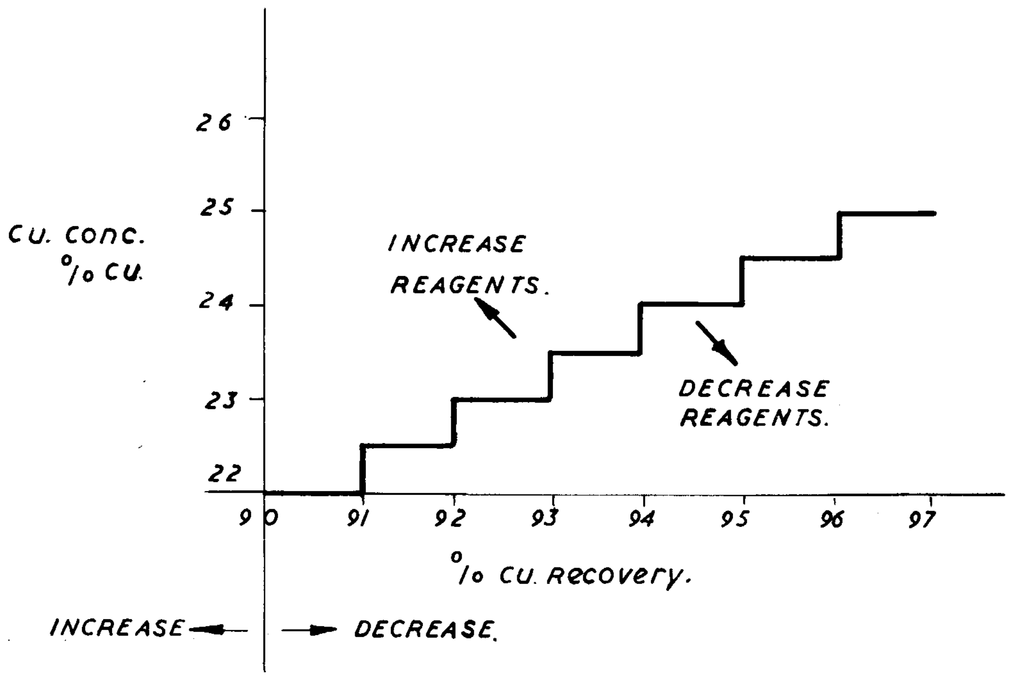


Fig. 3—First revision of strategy for copper control.

response to process disturbances of both internal and external origin.

At this time, it was decided to eliminate zinc grade of copper concentrates as a limiting factor for collector levels. It was found that the sacrifices in copper recovery required to reduce zinc contamination were too severe. A laboratory study revealed that the infrequency of changes in sulphur dioxide addition required to minimize the zinc content of copper concentrate did not justify the incorporation of these changes in the computer control strategy.

These first major revisions to the copper collector control strategy, including the matrix of optimum seeking grade/recovery relationships, and the elimination of zinc contamination as a control constraint, are illustrated in Fig. 3.

Although the computer control strategy developed to this point provided a satisfactory approximation of optimum copper flotation efficiency, the direct utilization of process economics was still considered a desirable goal. The second major revision of the control strategy was achieved by combining a copper flotation efficiency factor to determine the need for changes in the collector balance, with the interdependence of grade and recovery to determine the best direction for change. The efficiency factor was derived from up-dated smelter contract terms by the following calculation:

Efficiency %=(net smelter return÷gross metal value) × 100. In utilizing this strategy, the computer would monitor copper flotation efficiency changes, maintain the direction of collector adjustment on a rising efficiency, calculate the significance of copper concentrate grade and recovery on a falling efficiency and select the direction of collector adjustment most likely to promote a higher efficiency. The strategy would also alert process operators when the computer's best efforts failed to at least halt a falling efficiency. Action could then be initiated to adjust process variables not influenced by the computer control strategy such as flotation pulp levels, direction of scavenger concentrate to either middling retreatment or cleaning, and frother additions. This second major revision to the copper collector control strategy is illustrated in Fig. 4. Three months of on-stream testing have shown that this method of computerized collector control will maintain adequate copper flotation stability and ensure optimum economic efficiency.

Development of zinc control strategy

The development of effective computer control for zinc flotation reagents was inhibited by a basic misunderstanding of the relationship between activator and collector additions. Feed-back control of both copper sulphate and Reagent 317 additions caused metallurgical cycling in zinc roughing. A laboratory investigation showed that feed-forward proportioning of copper sulphate, at a threshold ratio to the zinc assay of the copper tailings, provided the best method of activation. However, feed-back collector control was essential to the search for optimum metallurgical performance. It was also necessary to extend computer control to zinc middling flotation to encompass a similar feed-forward/feed-back relationship between copper sulphate and Reagent 317 additions.

Although achieving a major improvement in flotation stability even the above four-point control scheme demonstrated a significant limitation to effective automatic control. Feed-back control of collector additions was based, in part, on the assay of the overall zinc tailing comprising the tails from rougher flotation and middling flotation. A laboratory test program verified the feasibility of combining re-ground middlings with rougher tailings in a scavenger flotation stage. This method for middlings retreatment did not inhibit flotation of zinc in the rougher circuit, produced a steady zinc head to scavenging and produced only one source of tailing from the zinc circuit. By incorporating these revisions to the zinc control strategy the selection of set points for flow limits and step sizes was readily accomplished.

A better understanding of the principles involved in zinc flotation permitted refinement of the computerized strategy for determining the need and direction for reagent adjustment to yield optimum economic metallurgy. The successful control of copper collector additions prompted the similar development of a zinc grade/recovery matrix, replacing the originally-set metallurgical targets. A study of optimum smelter contract economics, and a new knowledge of operating limitations in the zinc flotation circuits, permitted the rapid development of this matrix. The computer was programmed to call for either an increase or decrease in collector addition at each 0,5 per cent increment of grade and 1 per cent increment of recovery. For this evaluation the zinc recovery in the zinc circuit was calculated. No compensation was included for zinc recovered in copper concentrates. Copper sulphate additions were proportioned according to the zinc assay of the copper tailings. Metallurgical cycling, resulting from the matrix feed-back control of collector additions, was not unreasonable and cycle averages followed the economic optimum closely. Response to process disturbances was prompt and accurate. These first major revisions to the zinc reagent control strategy, including revised addition points, feed-forward copper sulphate control, and the matrix of optimum seeking grade/recovery relationships, are illustrated in Fig. 5.

Although the performance of the computer control strategy developed to this point was satisfactory, the successful application of smelter contract terms in copper collector control stimulated the evaluation of a similar method for zinc flotation reagents. The strategy, including the feed-forward copper sulphate control, is virtually identical in principle to that developed for copper collector control. Testing, although not thoroughly completed, indicates that an optimum economic control of zinc metallurgy can be achieved.

Development of silver-lead control strategy

With emphasis shifted towards copper and zinc metallurgy, little development of reagent control strategies for silver-lead flotation has been possible. The limits of existing computer and related instrumentation facilities have been reached. Additional

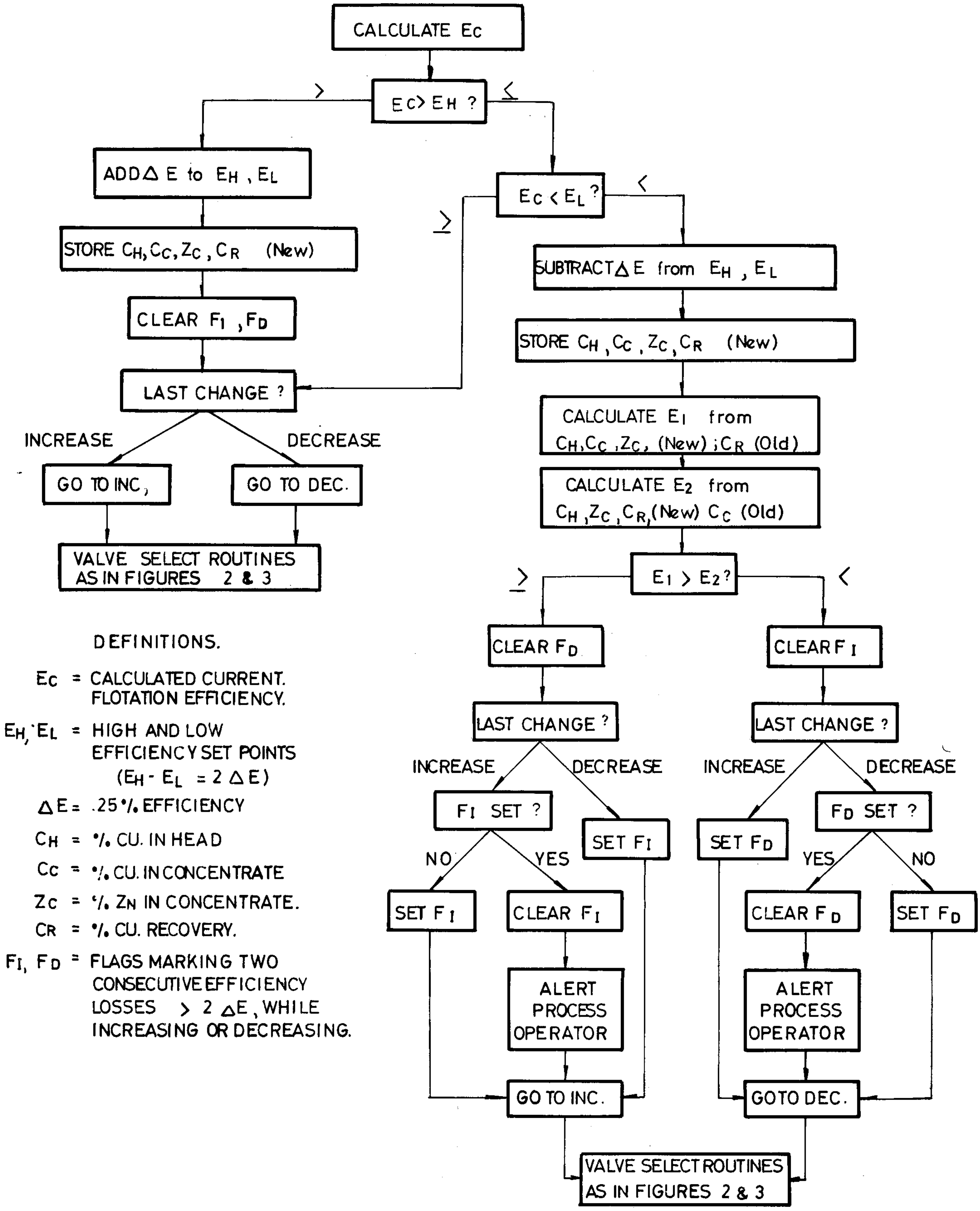


Fig. 4—Currently-used copper control strategy.

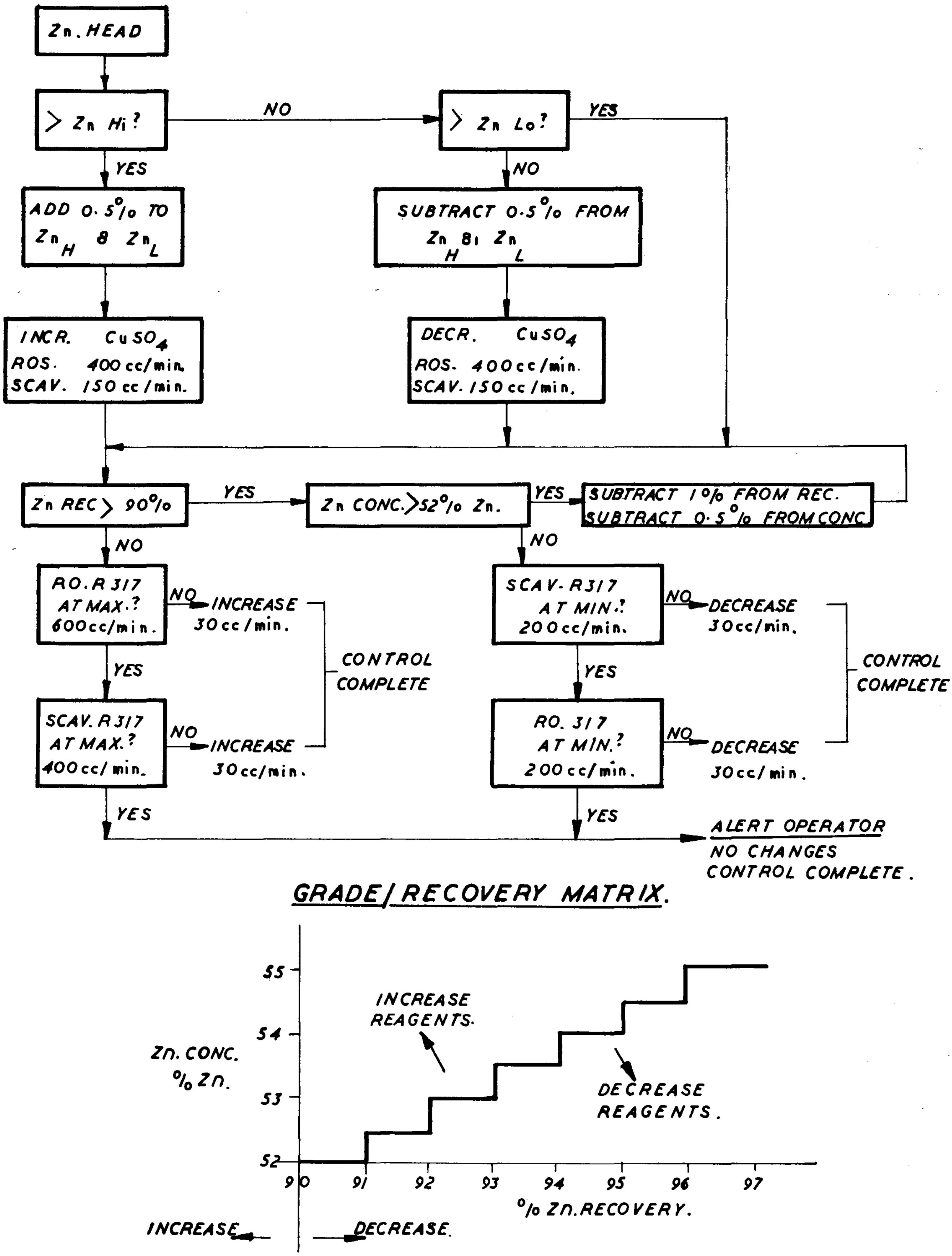


Fig. 5—Zinc control strategy.

hardware for eight control loops and another 4 096-word core memory module has been purchased. It is expected that on completion of this expansion the implementation of computerized reagent control for silver-lead flotation will be readily achieved.

Operator-control system interface

At the outset the process operator was recognized as perhaps the single most important element in the attempt to implement computer control. Every effort has been made to ensure that operator and computer work as a team. Communications to and from the automatic control system are provided in the central control room by an instrument display panel and the A.S.R.-33 teletype.

At the teletype, communication is one way only, that is, computer to operator. A typical teletype report shown below includes movements to and from maximum/minimum reagent flow limits on each flotation circuit, requests for operator assistance in improving flotation efficiency through manipulation of variables not within computer influence, shift average zinc recoveries in the zinc circuit and shift average flotation efficiencies:

07:47 B DIVISION ZN OFF MAXIMUM
07:59 PROBLEM WITH A CU GRADE
8HR. ZN. REC. AVG. A=96,45 B=96,65
8HR. A CU E=78,80

Typed displays of alarm conditions are accompanied by audio/visual alarming via buzzer and flashing light.

The display panel contains 24 instrument clusters, one for each control loop in the six flotation circuits. At this panel, operating supervisors can observe the reagent balance selected by the computer and note the current direction of revision, alter maximum/minimum flow limits and adjust step sizes, remove any loop from computer strategy, and implement manual overrides. The computer automatically imposes a freeze on reagent adjustment to any flotation circuit for which assay data are not available.

Temporary process disturbances may require operator influence through manual override. Any adjustments effected by process operators are recorded on a standard problem report form detailing the nature of the problem, corrective steps taken, and the success or failure of these steps. Problem reports are analysed by engineering staff and returned to the operators with appropriate comments. In this way, it is possible to ensure good communication between the control system, its operators, and its designers.

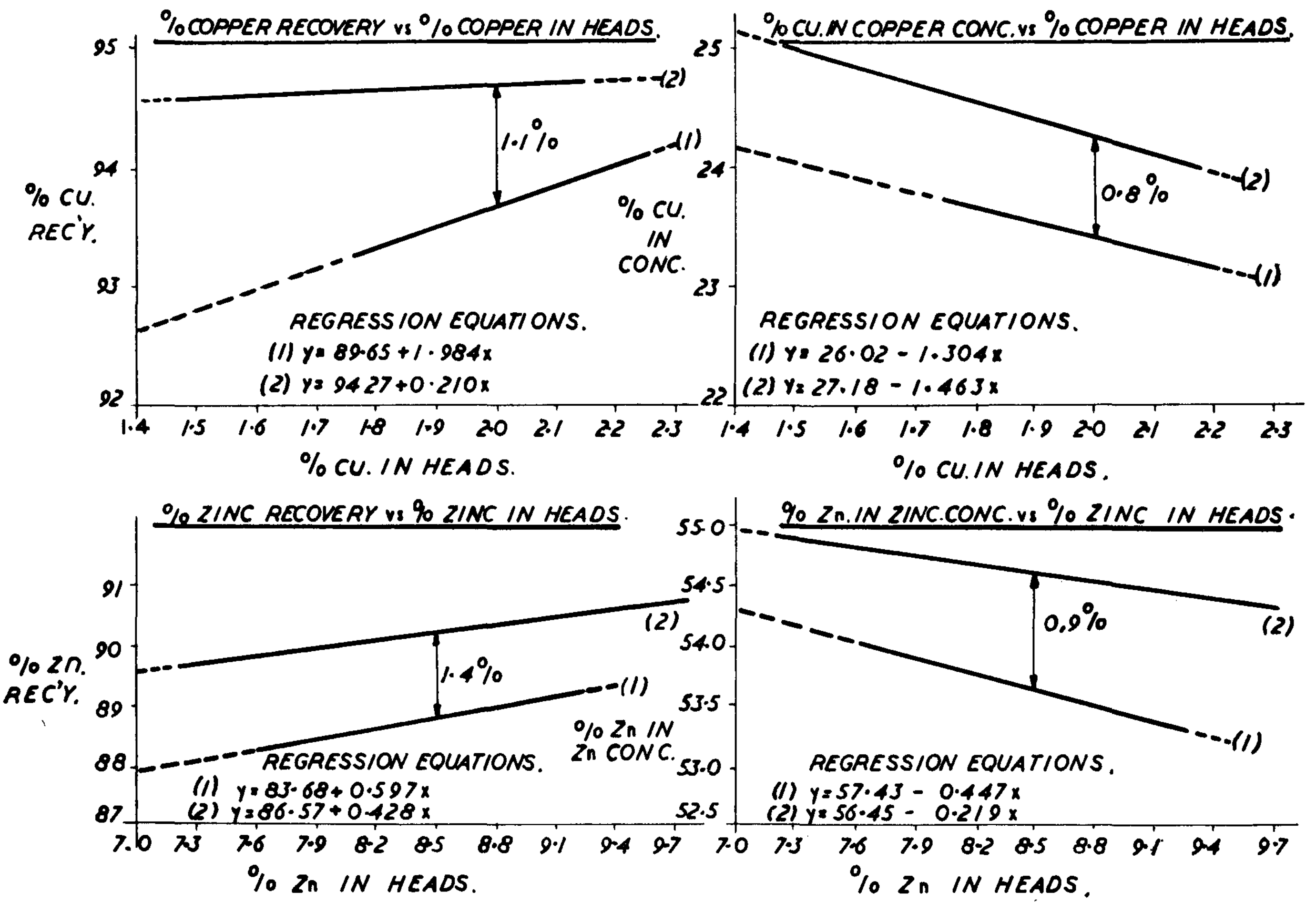


Fig. 6—Comparison of the efficiency of generation before and after the introduction of computer control.

SYSTEM COSTS AND METALLURGICAL RESULTS

At the time of writing the costs of implementing the system are expected to total $122 000. The cost breakdown is as follows:

(i)	*Hardware*	
	Honeywell 316 computer and peripheral equipment	$43 000
	Reagent control valves	49 000
	Operating control panel	10 000
		$102 000
(ii)	*Honeywell consultation*	20 000
	Systems total	$122 000

To illustrate metallurgical performance the periods January, 1969, to April, 1970, inclusive, and May, 1970, to July, 1971, inclusive, are compared in Fig. 6. At average heads of 2 per cent copper and 8,5 per cent zinc, copper recovery and copper concentrate grade show improvements of 1,1 per cent and 0,8 per cent, respectively. Zinc recovery and concentrate grade improved by 1,4 per cent and 0,9 per cent, respectively.

Although improvements in recoveries were realized almost immediately, reagent savings were not achieved until some experience had been gained with the system. To show the savings that have been gained in recent months the periods March to July, inclusive, for 1970 and 1971 are compared in Table II.

TABLE II

COSTS: $/TON ORE

	1970	1971
Copper flotation	0,129	0,124
Zinc flotation	0,372	0,295
TOTAL	0,501	0,419

Based on average heads of 2 per cent copper and 8,5 per cent zinc, the annual value of the metallurgical improvements and reagent savings are broken down as follows:

Copper	$588 000	Net smelter return
Zinc	710 000	Net smelter return
Reagent savings	188 000	
Total	$1 486 000	

After allowances for taxes, depreciation, and so on, the calculated payback period for the capital cost of the system is 0,17 years.

CONCLUSIONS

Successful application of computer control to copper and zinc flotation circuits has been achieved. Keys to this success were the availability of a very accurate and reliable on-stream X-ray analysis and the co-operation of the operating personnel in achieving an understanding of the objectives of the control strategy.

Optimum-seeking programs, devised to control principal reagents, have proven to be the most flexible for continuous circuit control. Indicated improvements in copper and zinc recoveries of 1,1 per cent and 1,4 per cent, respectively, surpassed the initial estimates of 0,5 per cent each. Reagent savings have been 16 per cent instead of the expected 10 per cent. Although not expected, improvements to copper and zinc concentrate grades of 0,8 per cent copper and 0,9 per cent zinc, respectively, have also been realized. We are confident that these successes can be maintained and possibly improved with further refinement. Additional savings are also expected when computer control is applied to the silver-lead-zinc flotation circuits.

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