COMPUTER-AIDED CONTROL FOR THE PRODUCTION OF FERROCHROMIUM IN A SUBMERGED-ARC FURNACE

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SYNOPSIS

This paper reviews the research project that was conducted by the National Institute for Metallurgy, in cooperation with Samancor, on the 48 MVA submerged-arc furnace at Ferrometals, Witbank. The research team was given the following objectives : to devise ways in which the furnace operators could obtain more accurate and extensive information, and to design closed-loop control where possible. Two dedicated microprocessor-based controllers and a minicomputer were used to implement the computer-aided control. As a result of the better understanding that was gained of the process, the rebuilding of the furnace, and the achievement of automatic control of the raw material and electrodes, the furnace production was increased to 125 per cent of the designed capacity.

Introduction

The growth of the ferro-alloy industry in South Africa is considerable, and since 1970 the electrical capacities of the furnaces have increased from approximately 20 MVA to today's 81 MVA. The production has increased in parallel, from less than 450 000 tons in 1970 to 1 111 100 tons of ferro-alloys in 1978 (1).

In theory, the economics of ferro-alloy production improve with increasing furnace size, but, as early as 1974, Mr J.J. Coetzee, at INFACON 74, pointed out new problem areas with large furnaces (2). He said : "The modern trend towards bigger furnaces and the associated larger capacities presented new problems. These large furnaces are relatively sluggish in following changes in operating conditions, thus demanding a far greater degree of expert control than necessary with smaller furnaces". Mr Coetzee also sounded a warning; he felt "that the installation of computer control on a furnace did not mean that one could now neglect the prerequisites of good furnace operation, namely the chemical and physical characteristics of raw materials in a furnace burden". He was, of course, referring to Amcor's experiences with the newly installed 48 MVA furnaces producing ferrochromium and ferromanganese.

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For some years the National Institute for Metallurgy (NIM) has made an intensive study of the metallurgy of ferro-alloy production in electric furnaces. However, when the investigation of computer-controlled submerged-arc furnaces was conceived, there was still much about the process that was not understood, and it was felt that further progress could be made only through the study of a well-instrumented and controlled furnace. Many aspects of furnace operation remained unclarified since NIM's studies under the conditions prevailing at the time had involved the danger of serious losses in production.

Implementation of the data-logging computer system

When selecting a suitable computer system for research purposes, one has to decide between flexibility and reliability. NIM decided to use a general-purpose minicomputer system, and designed its own flexible software programmes for the data logging and correlation of these data into suitable reports (6). The computer was housed in a sealed-off part of the existing control room at Ferrometals, and was connected to the plant through signal converters and isolators (7).

The data-acquisition package was written in FORTRAN 5, being based on a point record system in which each variable to be scanned was assigned a point record that defined all the functions to be performed on that variable during the scan. An off-line interactive programme allows the user to rearrange all the point records.

The operations performed during each scan include the following :

(i) sampling of analogue channels, (ii) conversion to engineering units, (iii) calculation of derived variables, (iv) limit checking and reporting, and (v) averaging and calculation of statistical data. The conversion to engineering units is based on the equation

$$\text{Result} = A + (B \times \text{Raw value}) + (C \times \text{Raw value})^2,$$

where A, B and C are constants entered during the generation of the off-line point records. The data collected for each variable during each shift consist of the mean, standard deviation, maximum value, and minimum value. The set of data for each shift is stored on a wrap-around disc file that can carry the data from all the shifts worked over seven-and-a-half days. In addition to the storage of shift data, each minute the averages of 32 variables are stored on another wrap-around disc file that can similarly accommodate data accumulated over seven-and-a-half days. Every week all the information that has been collected is copied onto another disc and then stored on magnetic tape for subsequent retrieval and further processing.

The processed data can be accessed in three forms : by the minute, by the shift (8 hours), or by the day. The minute report is available from the console on demand (Table 1).

TABLE 1

Specimen of a minute report

HOURS	MINUTES			
REAL POWER	MW	35,525		
REACTIVE POWER	MVAR	34,791		
APPARENT POWER	MVA	50,081		
POWER FACTOR		0,709		
AV RESISTANCE	MOHM	1,012		
TAP POSITION		20,000		
ELECTRODES		1	2	3
PRI CURRENT	KA	0,931	0,933	0,962
SEC CURRENT	KA	101,112	101,343	104,503
VOLT EL-B	V	117,902	129,604	130,842
POWER FACTOR		0,874	0,902	0,723
POWER	MW	10,46	11,62	9,92
RESISTANCE	MOHM	1,023	1,131	0,908
REACTANCE	MOHM	0,605	0,543	0,863
HOIST POS	M	0,380	0,481	0,637
GAS ANALYSIS				
% CO 65,194	%CO_2 9,093	%H_2 6,110	%O_2 0,333	%N_2 19,9

		GAS PLANT A	GAS PLANT B
RAW GAS TEMP	DEG C	473,361	556,749
CLEAN GAS TEMP	DEG C	54,168	66,323
CLEAN GAS PRESS	MM WG	110,273	121,981
FLOW D. PRESS	MM WG	7,124	19,686
GAS DENSITY	KG/M3	0,905	0,905
TOTAL GAS FLOW	M3/HR	2678,881	5127,692
DRY GAS FLOW	M3/HR	2194,028	4269,531
DRY GAS FLOW NORM	NM3/HR	1516,056	2771,211
CARBON REDUCTION	KG/HR	1220,323	

The shift report (Table 2) is used as a check on the stability of the furnace as shown by some data (e.g., current, resistance, and power per phase), and for the development of empirical models.

TABLE 2

Specimen of a shift report

Process variable units

REALPOWR	MW
REACPOWR	MVAR
APP POWR	MVA
TAP NO.	
AVE RES	MOHM
AVE REAC	MOHM
EL CURR1	KA
EL CURR2	KA
EL CURR3	KA
EL POWR1	MW
EL POWR2	MW
EL POWR3	MW
EL RES1	MOHM
EL RES2	MOHM
EL RES3	MOHM
EL REAC1	MOHM
EL REAC2	MOHM
EL REAC3	MOHM
HOISPOSN1	MTRS
HOISPOSN2	MTRS
HOISPOSN3	MTRS
GAS FLOWA	NM3
GAS FLOWB	NM3
CARBFLOW	KG
MASSFLOWCO	KG
$MASSFLOWCO_2$	KG
$MASSFLOWO_2$	KG
$MASSFLOWH_2$	KG
$MASSFLOWN_2$	KG
MOIS1	%
MOIS2	%
RAW GAS A	DEG
RAW GAS B	DEG
HEATFLOW1	
HEATFLOW2	
HEATFLOW3	
ARC FCTR1	
ARC FCTR2	
ARC FCTR3	

SEC VOLTL-N	VLTS
SEC VOLTL-N	VLTS
SEC VOLTL-N	VLTS
ELCNRES1	OHMS
ELCNRES2	OHMS
ELCNRES3	OHMS
ELCNREAC	OHMS
ELCNPOWR1	MW
ELCNPOWR2	MW
ELCNPOWR3	MW
FURNACE OFF FOR	

Data, together with models that have proved useful, are incorporated in the daily report. The report on any particular day's operation is available on demand for up to 7½ days before it is over-written. The format of a daily report is shown in Table 3.

TABLE 3

Specimen of a daily report

DAILY REPORT	HOURS MIN	DATE		
FURNACE TIME OFF	HRS 00			
AVERAGE POWER	MW			
TOTAL POWER	MWHR			
GAS FLOW	NM3/HR			
TOTAL MATERIAL	TONNES			
TOTAL BATCHES				
EXTRA BATCHES				

00%
00% 00% 00%
00% 00% 00%

ELECTRODES		1	2	3
AVERAGE CURRENT	KA			
MEASURED POWER	KWHR			
CALCULATED POWER	MWHR			
CONSUMPTION RATE	CM/MW			
CONSUMPTION	CM			
SLIP	CM			
LENGTH	M			
LENGMOD1	M			
PENETRATION	M			
LENGMOD2	M			
AV HOIST POS	M			
AV RESISTANCE	MOHM			
TIP TO TAP HOLE				

MASS BALANCE

RAW M	%	CR_2O_3	FEO	SIO_2	CAO	MGO	AL_2O_3	CO_2	C	VOL	H_2O
ANAL 1											
ANAL 2											
ANAL 5											
ANAL 6											
ANAL 7											
ANAL 8											
ANAL 9											
ANAL 10											
	TONNES										
MAT 1											
MAT 2											
MAT 5											
MAT 6											
MAT 7											
MAT 8											
MAT 9											
MAT 10											
TOTAL											

SLUDG
SLAG
METAL

METAL
METAL ANAL
ACT SLAG ANA
SLUDG ANAL

METAL PROD.TONNES CALC SI ANAL % SI IMB %

SLUDG
SLAG
METAL
METAL

METAL ANAL
SLAG ANAL
CHROME LOSS % IRON LOSS %

MGO/AL_2O_3 MGO/CAO MGO/SIO_2

CALC
ACT

CARBON FLOW. TONNES THEO MEAS DIFF %

METAL PROD. TONNES CARBON EXCESS % =

POWER CONSUMPTION MHW/TON SLAG/METAL

METAL+SKROT.TONNES P.C. S/M

ACTUAL METAL PRODUCTION. TONNES

METAL ACCUMULATION TOTAL ACCUMULATION

Results that influenced the future of the project

After having established a reasonably reliable data-logging facility with the computer, it became apparent that the raw-material feed differed considerably at times from the requested formula, that the weighing accuracy was not sufficient, that compensation was required for the moisture in the reducing agent, and that the logging facilities were insufficient. In addition, it became obvious to the research team that the inductive reactance in the furnace influenced the operation of the electrical circuit and the metallurgical operation (8). Thus, some form of stricter control, possibly automatic, was needed.

Although the minicomputer could be expanded and a system similar to that installed at NIM could be used for the development of new software, the reliability of the plant computer at the time was not sufficient to encourage additional process-control packages to be implemented on a permanent basis. NIM therefore decided that on-line control functions should be implemented by a control system based on microcomputers.

Implementation of the control system

As a first step in the control, two microcomputers were used to accurately measure the raw material fed to the furnace and to control it. This control system includes the following features :

(i) Two nuclear moisture meters monitor the moisture content of the coke, and generate signals to the remote terminal, which makes feed-forward corrections to the setpoints and then transmits the corrected setpoints to the controller-logger.

(ii) Errors in the recipe during batching are recorded and compensated for in subsequent batches.

(iii) The operator enters the required setpoints into the remote terminal by means of thumbwheel switches.

(iv) Any output is printed on a hard-copy printer by the terminal.

(v) The information is sent to the minicomputer batch by batch. If the computer is not available, the data can be accumulated for up to 8 hours.

(vi) The feeders automatically change from the feeding of coarse to the feeding of fine material when the quantity of material fed is within a constant number of kilograms from a setpoint. (The limit for coarse material can be set by the programme).

(vii) Because of the experimental nature of the installation, it was necessary for the operator to be able to switch back to the original automatic or manual modes of operation. The system therefore has three modes of operation : COMP (the system based on the micro-computer), AUTO, and MAN. It should be noted that the system based on the microcomputer continues to log and perform inventory functions irrespective of the mode of operation chosen by the operator.

The system has proved to be very reliable, and it can be concluded that a microprocessor is generally suitable for industrial applications - even when the environment is particularly hostile. It was noted that, during logging, the system typically reads to within one kilogram of the calibrated value. Before control by the microcomputer-based system was introduced, it was observed that errors due to overshoot and undershoot usually amounted to about 4 per cent, and were often as high as 15 per cent. Since the introduction of the system, the improvement in accuracy has been virtually tenfold. The system has the advantages that the moisture content of the reducing agents can be compensated for automatically, and the constituents of the feed closely monitored.

The weighing system was controlled almost exclusively by the microcomputer once this had been installed. In addition, as operators were no longer required to make manual adjustments for the moisture content of the reducing agent, their work load was reduced considerably.

The second area requiring attention was the implementation of better control over the electrodes. As this topic is discussed in detail in a paper by Stewart and Barker (9), only the basic implementation and the results are discussed here.

Measurements of the resistances in each phase of the circuit of a furnace cannot be based on the inter-electrode voltages and electrode currents without voltage connection to the star point. However, the resistance can be estimated approximately if some assumptions are made, and this estimate is more accurate and reliable than a conventional direct measurement. In addition, because no connection to the metal bath of the furnace is required, all the measurements can be taken on the primary sides of the furnace transformers, where measurements of the voltage and current are less prone to error. This is the basis of the measurements system used by the NIM electrode-controller, which then exercises direct control on the movement of the electrodes based on these estimated resistances and the resistance setpoints entered in the controller, thus maintaining the balance in the furnace.

The operation of any submerged-arc furnace is subject to certain design limitations. For example, the current in an electrode must not exceed a predetermined level for a prolonged period, and a transformer must not exceed its volt-ampere rating. If the furnace is to be operated at maximum power to yield maximum production, one or more such limitations will apply. The NIM electrode-controller also automatically controls the tap changers on the transformers so that maximum power is supplied to the furnace within the various limits of operation. These limits of operation, like the resistance setpoints, must be entered in the controller.

In addition to the basic control functions described above, the NIM electrode-controller also has facilities for baking the electrodes, and displays useful information such as the resistances it calculates. It is also able to detect certain fault-indicating conditions in the operation of the furnace, and to warn the operator accordingly.

The algorithm for the electrode-controller was first developed on the mini-computer (10), where it went through several stages of development. A limited form of the algorithm ran on the minicomputer successfully for several months before it was implemented in a microcomputer-based controller that was subsequently installed on a permanent basis on a plant (11).

The electrode-controller has fulfilled all expectations. The operation of the furnace is no longer adversely affected by imbalances due to high reactance, the incidence of electrode breakages has decreased considerably, and the operators find their tasks less onerous because they no longer need to attend continually to electrode control. In addition, there has been a notable increase in the production of the furnace.

As described above, both controllers can operate on their own and do not require a supervisory system for process control. But both systems have been connected to the minicomputer so that comprehensive reporting of data can be done for the personnel who supervise the furnace operation (see Figure 1). With the above equipment operative, the investigation in much more detail, of the dynamic behaviour of the operation became possible. However, it was still necessary for the operator to check on the signals received from the operation to ascertain their nature, accuracy, and adequacy for the possible application. It was only at that stage of the investigation that a study became possible of whether the process could be understood, modelled, and subsequently controlled through the facilities provided. This use of the computer as a tool to improve the day-to-day operation of the furnace and to assist the production personnel was termed "computer-aided operation".

Computer-aided operation

Large electric-smelting furnaces have particular operating characteristics that must be learnt from experience. Once control over the raw material and electrical setpoints has been achieved, it is still necessary for the following factors to be taken into account if the furnace is to operate efficiently :

1. the type and blend of raw materials,
2. the degree of screening required,
3. the size, type, and quantity of reducing agent,
4. the constraints on good baking of the electrodes, and
5. the electrical setpoints.

Some factors used in the evaluation of furnace operation are average power input, power consumption per ton of alloy, grade of product, ease of tapping, and down-time. Most of these are included in the daily report (Table 3). Computers are unbiased in their logging and reporting functions (operators' log sheets are notoriously biased), and problems can often be solved before they assume major proportions. The circumstances leading to the breakage of an electrode can be studied in detail from data recorded on the wrap-around disc file by use of the plotting or printing facilities. For example, if the composition of the metal or the slag does not meet the specifications, the error can be related back, say, to an incorrect recipe or an unauthorized additive.

It was found that, once a correct mix of raw materials had been achieved, the length of the electrode beneath the contact shoes was the most important factor in the stable operation of the furnace. The computer was able to provide the type of on-line data required for an examination of the reasons why the length of the electrodes was so important, and of how this length could be predicted and controlled. Enormous quantities of data were analysed by the computer, which also provided the dedicated control necessary for the testing of hypotheses and algorithms.

Considerable research on the erosion of electrodes and the effects of this erosion on the operation of a furnace led to a greater appreciation of the importance of where the power is dissipated within the furnace. Models were developed that explained the residence time of material and the build-up of metal within the furnace. The distribution of the power dissipated under an electrode was found to depend on the height of the electrode above the metal bath and on the resistivity of the material between the electrode and the bath. On-line perturbations were used in the estimation of the resistivity of the region immediately beneath the electrode. The model predicted that the resistivity in this region would be most important, and this was confirmed by the perturbations. One of the main factors influencing the degree of arcing was the resistivity, which was found to be related to the flow-rate of the raw materials round the particular electrode and the drainage pattern beneath it. The metallurgical interactions in this region are complex, and are the subject of continuing research. Some of these results have been published (12).

Aids to metallurgical planning

The successful operation of a high-carbon ferrochromium furnace depends on the correct proportioning of the raw materials in the burden. The proportions for the blending of the raw materials can be calculated from the average chemical analyses of the components of these materials, allowance being made for fluctuations in their composition. This results in stable operation of the furnace, a grade of metal of the required specifications, and slag having a composition that is restricted to certain limits identified with good furnace behaviour. Representative samples and reliable analyses of the various raw materials, particularly carbon, are essential if adequate control of the mass balance is to be achieved.

The availability of a computer on the furnace led to the development of a set of programmes for the calculation of material balances and heat balances. Two computer programmes were developed for the compilation of mass balances. One programme was used for the formulation of the feed which consists of ores, fluxes, and carbonaceous reducing agents, and was based on the desired output (the design mass balance). The other programme was used for the prediction of the output from the furnace, and was based on the total input and analyses of the raw materials (the performance mass balance).

The desired accuracy in the weighing of the raw materials could be defined only once the calculation for the design mass balance had been completed. Table 4 shows the accuracy required in the weighing of the various raw materials.

Tables 5 and 6 show examples of the print-outs of a design mass balance and a performance mass balance respectively.

Another computer programme was developed for the calculation of heat balances. The programme was based on thermodynamic considerations of the chemistry of the process and on the total masses of the chemical components entering the furnace. Good agreement was observed between the predicted output based on the calculation of the mass balances and the predicted output based on the heat-balance calculation using the average operating load and the theoretical power consumption per ton of high-carbon ferrochromium (see Tables 5 and 6). The details relating to the development of the mass- and heat-balance programmes are to be given elsewhere (13).

The use of the mass- and heat-balance calculations in the prediction of metal production, and the comparison of the predicted value with the actual output of hot-weighed metal, led to the development of the metal mass-flow model. The metal produced within the furnace during a day does not necessarily leave the furnace in the same time interval. Metal can be built up or be washed out, or both. The build-up of metal was found to be a problem in furnace operation. A hypothetical pattern of metal flow is shown in Figure 2. The early detection of a build-up can therefore forestall a serious problem.

Type of raw material	Component	Phase	Composition range considered %	Permitted deviation %	Accuracy required in weighing %	Actual mass per standard quantity of mass balance kg
Chromite	All	Slag, metal	All	1,0	0,5	10 in 2000
Quartz	SiO_2 SiO_2	Metal as Si Slag as SiO_2	3,5 to 4,5 24 to 26 (MgO/SiO_2 = 1,0)	0,5 1,0	3,5 6,9	3,6 in 100
Uncalcined dolomite	MgO	Slag as MgO	24 to 26 (MgO/Al_2O_3 = 1,0/1,5)	1,0	13,1	26,2 in 200
Limestone	CaO	Slag as CaO	5 to 6 (MgO/CaO = 5,0/5,5)	0,5	13,6	6,8 in 50
Carbonaceous reducing agent (for reduction and resistance)	Fixed C (dry) H_2O Ash	Liquid : solid Slag as SiO_2	 10 to 15 (suggested) 24 to 26 (suggested)	 1,0 (suggested) 1,0 (suggested)	0,5 Varies with percentage of ash and moisture	20 in 400 20 in 400

TABLE 4 Accuracy required in the weighing of raw materials for the production of high-carbon ferrochromium

DATE 21/ 2/79 DESIGN SMELTING BALANCE

RAW MATERIALS	%	STD BATCH	CR2O3	FEO	SIO2	CAO	MGO	AL2O3	CR	FE	SI	C
ORE1	85.04	1700.89	41.10	22.90	5.60	1.10	11.40	14.30				
ORE2	10.42	208.44	37.10	18.20	14.80	3.90	12.00	10.00				
ORE3	4.53	90.67	39.90	15.30	11.40	1.10	18.90	8.60				
QUARTZ	3.35	66.98	.00	.40	99.00	.20	.10	.40				
DOLM	5.03	100.67	.00	.00	1.40	56.20	1.40	.40				
SERP	4.25	85.08	.70	5.90	40.00	1.00	37.50	.90				
RED1	19.77	395.36	.00	2.00	8.50	.60	.40	4.90				81.60
TOTAL			40.66	22.73	13.59	4.39	13.55	14.63				
+ SKROT			42.17	23.40	15.54	5.11	15.78	17.05	10.13	6.84	.38	1.37
TO METAL			31.27	18.58	1.71	.00	.00	.00	21.39	14.44	.80	2.88
+ SKROT			38.57	26.34	2.91	.00	.00	.00	31.52	21.27	1.18	4.25
TO SLAG			9.05	4.03	11.74	4.35	13.36	14.51				
+ SKROT			10.56	4.70	13.70	5.08	15.58	16.93				
SMOKE LOSS			.34	.11	.14	.04	.19	.12				
+ SKROT			.42	.16	.23	.04	.19	.12				
ANALYSIS			15.87	7.07	20.58	7.63	23.41	25.44	53.32	35.99	2.0	7.19

MGO/AL2O3 RATIO = .92
MASS OF SLAG = 57.05
CR/FE RATIO = 1.60
MASS SKROT = 28.50
FINAL SLAG MASS = 66.55

MGO/CAO RATIO = 3.07
MASS OF METAL = 40.11
SLAG/ALLOY RATIO (NO SKROT)= 1.42
SLAG/ALLOY RATIO (PLUS SKROT) = 1.13
FINAL METAL MASS = 59.11

MGO/SIO2 RATIO = 1.14
EXCESS CARBON(%) = 13.73
EXCESS CARBON(KG/BATCH)= 44.29

HEAT BALANCE TABLE
(BASED ON THE PRODUCTION OF ONE METRIC TON OF CHARGE CHROME)

HEAT PROVIDED FOR:	K CALS	K.W.H.
HEATING OF RAW MATERIALS	992832.20	
HEATING OF SKROT METAL	81823.94	
REDUCTION REACTIONS	1161039.00	
FUSION OF METAL	77605.06	
FUSION OF SLAG	275722.10	
SUPER-HEATING OF SLAG	34030.12	
HEAT INPUT	2623052.00	3048.51
MAXIMUM HEAT LIBERATED FROM (CO) (PRE-HEATING MIX)	136446.20	158.58
	2486605.00	2889.93
HEAT LOSSES IN ELECTRODES		306.90
FINAL TOTAL		3196.83

THEORETICAL TONS (OF ALLOY PRODUCT) PER DAY = 150.15 AT 20.0 MW LOAD AT 80.00 KAMPS

TABLE 5 Printout of a design for a mass balance

TABLE 6 Printout of a design for a performance mass balance

DATE 21/ 2/79

SMELTING BALANCE

		CR2O3	FEO	SIO2	CAO	MGO	AL2O3	CR	FE	SI	C
1 ORE	326.40	41.10	22.90	5.60	1.10	11.40	14.30				
2 ORE	40.00	37.10	18.20	14.80	3.90	12.00	10.00				
3 ORE	17.40	39.90	15.30	11.40	1.10	18.90	8.60				
4 QUARTZ	11.50	0.00	.40	99.00	.20	.10	.40				
5 SERPENTINE	19.20	.70	5.90	40.00	1.00	37.50	.90				
6 LIME	19.20	0.00	0.00	1.40	56.20	1.40	.40				
7 REDUCTANT	74.40	0.00	2.00	8.50	.60	.40	4.90				81.60
TOTAL		156.07	87.35	51.84	16.79	53.08	56.11				60.71
TOTAL & SKROT		157.57	88.03	54.07	17.36	55.36	58.15	10.07	6.77	.38	62.08
TO METAL		117.95	69.77	-5.16	0.00	0.00	0.00	90.70	60.97	-2.03	11.62
TO SLAG		38.88	17.32	57.41	17.05	52.13	57.10				
SMOKE LOSS		.74	.93	1.79	.39	2.99	1.16				
ANALYSIS(CALC)		15.87	7.07	23.43	6.96	21.28	23.30	56.52	37.98	-1.69	7.19
ANALYSIS(REP)		15.87	7.07	23.43	6.00	24.07	21.47	52.99	35.65	2.00	7.19
ANALYSIS(COR)								53.01	35.63	2.00	7.19

MASS OF SLAG = 235.97 METAL(CALC) = 142.67 METAL(REP)= 140.00 METAL(CORR) = 152.10

CR/FE RATIO = 1.60 SLAG/ALLOY RATIO (NO SKROT)= 1.55

RECOVERY AS %(ORE)

CHROME = 74.85 FERRO = 79.26 SILICON = -9.54

RECOVERY AS %(ORE+SKROT)

CHROME = 77.77 FERRO = 81.78 SILICON = -11.44

RECOVERY AS %(REPORTED ANALYSIS)

CHROME = 63.14 FERRO = 66.47 SILICON = 11.72

MGO/AL2O3 REP: 1.12 CALC: .92

MGO/CAO REP: 4.01 CALC: 3.09

MGO/SIO2 REP: 1.03 CALC: 1.14

METAL LOSS AS % = 13.40 SIO2 IMBALANCE = -11.68 TONS = -21.60 %

MASS SKROT = 28.50 SLAG/ALLOY RATIO (PLUS SKROT) = 1.43

FINAL SLAG MASS = 245.02 FINAL METAL MASS = 161.67

EXCESS CARBON = 26.45 S/M IN SKROT = .50 FINAL METAL MASS(CORR) = 171.10

EXCESS CARBON(COR) = 13.73

HEAT BALANCE TABLE

(BASED ON THE PRODUCTION OF ONE METRIC TON OF CHARGE CHROME)

HEAT PROVIDED FOR:	K CALS	K.W.H.
HEATING OF RAW MATERIALS	1228262.00	
HEATING OF SKROT METAL	28094.44	
REDUCTION REACTIONS	994104.06	
FUSION OF METAL	77155.44	
FUSION OF SLAG	328060.13	
SUPER-HEATING OF SLAG	42405.65	
HEAT INPUT	2698080.00	3135.71
MAXIMUM HEAT LIBERATED FROM (CO) (PRE-HEATING MIX)	122228.25	142.05
	2575851.00	2993.65
HEAT LOSSES IN ELECTRODES		317.91
FINAL TOTAL		3311.56

THEORETICAL TONS (OF ALLOY PRODUCT) PER DAY = 144.95 AT 20.0 MW LOAD AT 80.00 KAMPS

Results and conclusions

While gaining an understanding of the production of ferrochromium in a submerged-arc furnace, the research team attended to many other items such as the slipping of electrodes, the building of a reliable slipmeter, and the automation of raw-material sampling. In addition, much was learnt about the installation of reliable control devices and computer facilities on a ferro-alloy production unit.

The team achieved the objectives of this particular study which were as follows : to devise ways in which operating personnel could be informed about the conditions prevailing in a furnace, to design closed-loop systems for the control of raw materials and power supply, and to establish relatively stable operation.

Figure 3 gives an impression of the increase in production (to 125 per cent of the designed capacity) achieved as a result of the better understanding of internal processes (A to B), the introduction of elementary control (B to C), the rebuilding of the furnace, and the provision of automatic control of the electrodes (D to E).

Acknowledgement

This paper is presented by permission of the National Institute for Metallurgy. The investigation reported here was marked by very close cooperation between the staff of Ferrometals and of the National Institute for Metallurgy. This teamwork proved very valuable; without the contribution of each member of the combined team, the considerable increase in production would not have been achieved.

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FIGURE 1

While the gathering and presentation of data goes on continuously in the foreground partition of the computer memory, the background partition can be used for the compilation of daily reports, the calculation of metallurgical mass and heat balances,and other related computations. The overall arrangement depicted in Figure 1 shows the foreground and the background partitions of the computer as separate units. This has been done for the purpose of clarity; in practice, there is only one computer.

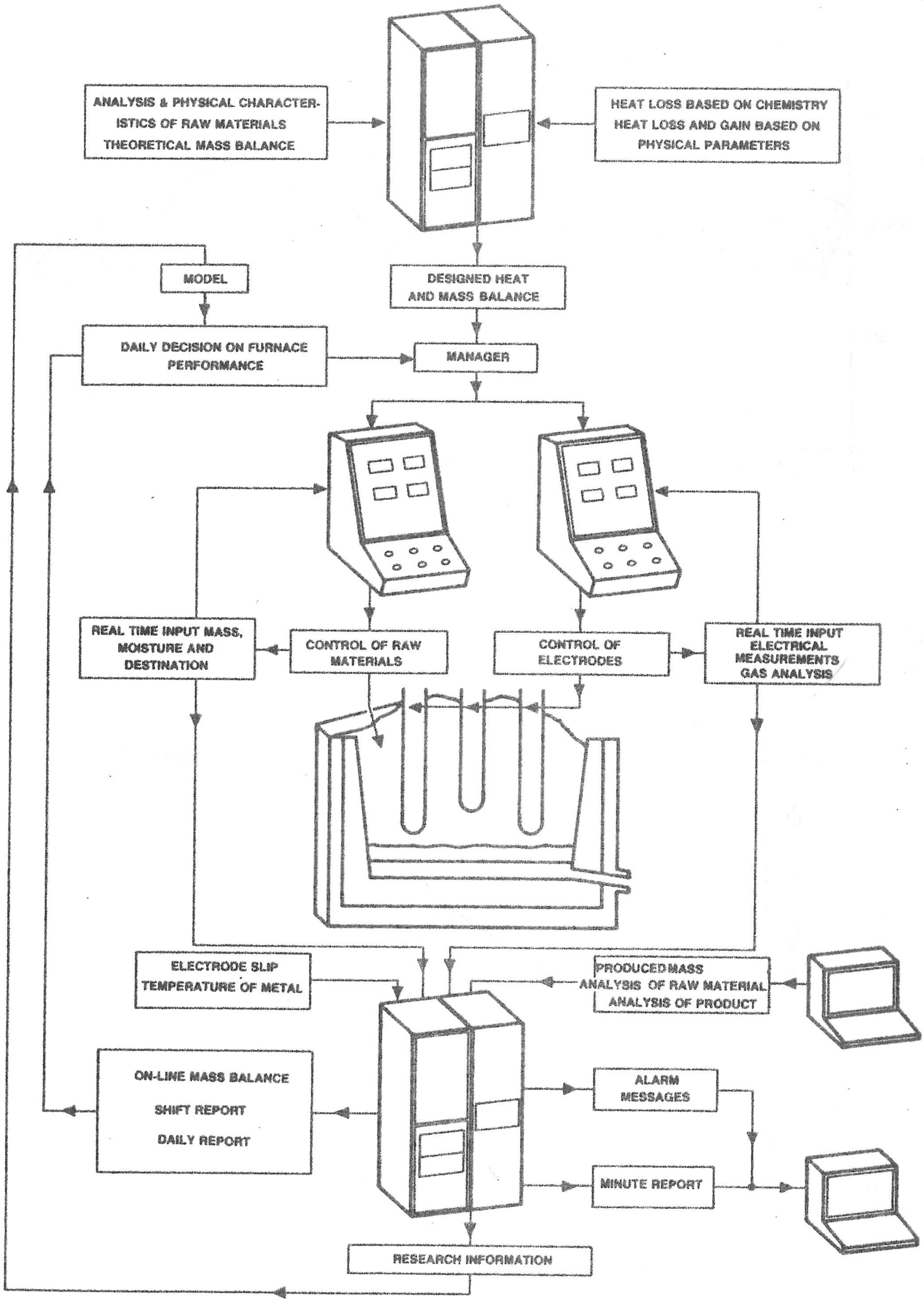
ANALYSIS & PHYSICAL CHARACTERISTICS OF RAW MATERIALS
THEORETICAL MASS BALANCE
HEAT LOSS BASED ON CHEMISTRY
HEAT LOSS AND GAIN BASED ON PHYSICAL PARAMETERS
MODEL
DESIGNED HEAT AND MASS BALANCE
DAILY DECISION ON FURNACE PERFORMANCE
MANAGER
REAL TIME INPUT MASS, MOISTURE AND DESTINATION
CONTROL OF RAW MATERIALS
CONTROL OF ELECTRODES
REAL TIME INPUT ELECTRICAL MEASUREMENTS GAS ANALYSIS
ELECTRODE SLIP
TEMPERATURE OF METAL
PRODUCED MASS
ANALYSIS OF RAW MATERIAL
ANALYSIS OF PRODUCT
ON-LINE MASS BALANCE
SHIFT REPORT
DAILY REPORT
ALARM MESSAGES
MINUTE REPORT
RESEARCH INFORMATION

FIGURE 1

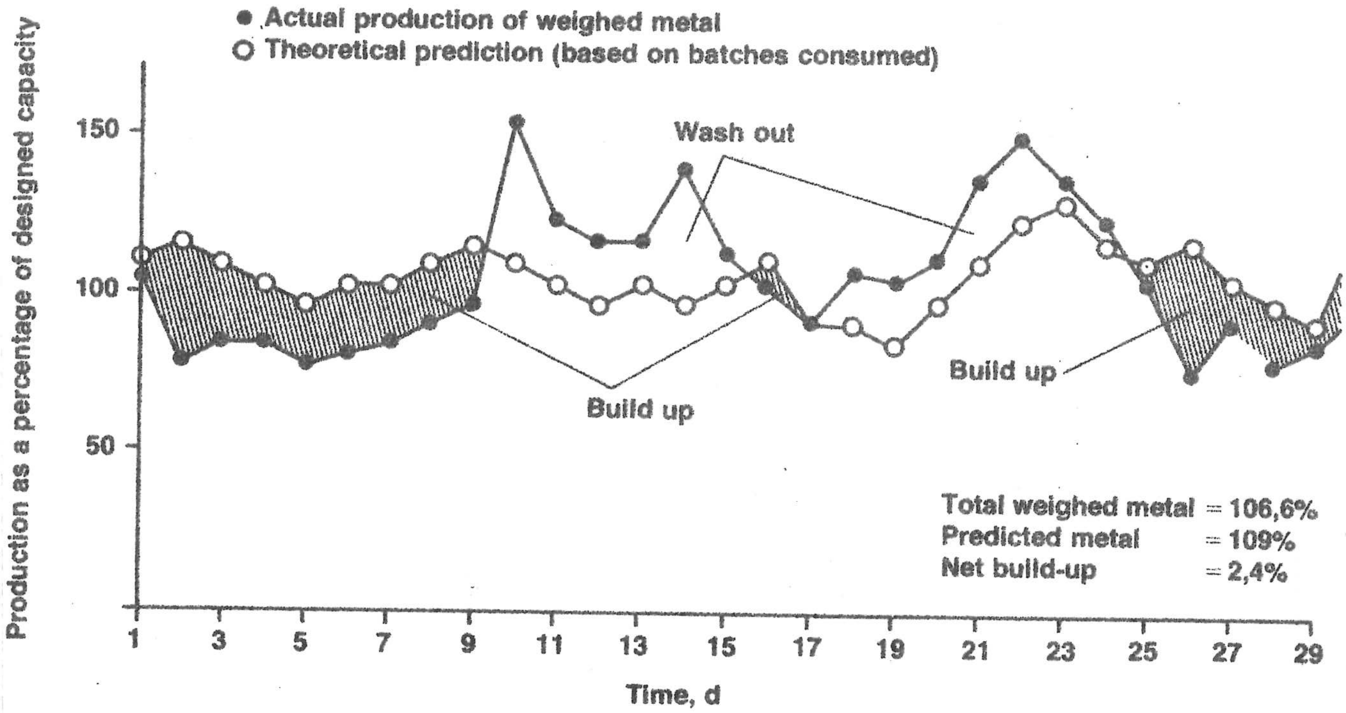

FIGURE 2 The pattern of the flow of metal

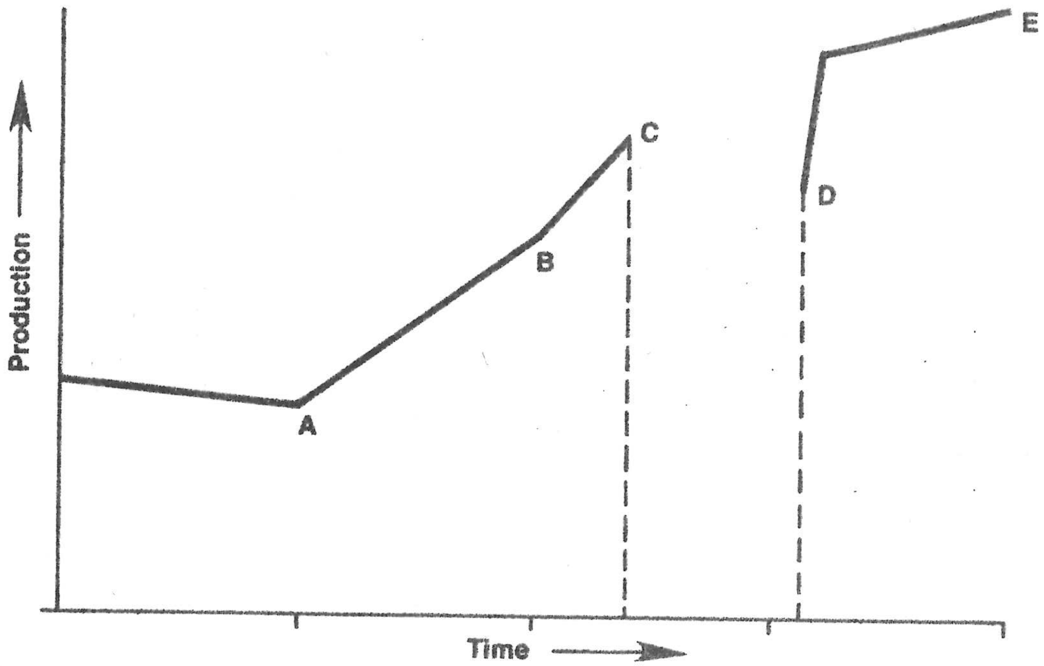

FIGURE 3 An impression of the increase in production during the investigation