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Vienna International Centre, P.O. Box 300, 1400 Vienna, Austria
Tel: (+43-1) 26026-0 · www.unido.org · unido@unido.org

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[illegible] DEVELOPMENT OF CONCURRENT TOP AND
[illegible] STEEL MAKING - CONTRACT NO 84/66

FINAL REPORT

MEFOS

MEFOS
METALLURGISKA
FORSKNINGSSTATIONEN

Forsknings-uppgift:	Konto:	Datum:	Reg nr:
UNIDO/INDIA	4449	1985-05-09	M85044K

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INDIA.

Subject: DP/IND/81/036 - DESIGN DEVELOPMENT OF CONCURRENT
TOP AND BOTTOM BLOWN CONVERTER STEEL MAKING -
CONTRACT No. 84/66

FINAL REPORT

by

Bertil Berg, Mikael Brunner, Bodil Dahlberg,
Erica Granberg, Pekka Kuusela and Nils-Olov Lindfors

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    B. Berg
    M. Brunner
    B. Dahlberg
    E. Granberg
    P. Kuusela
    N.O. Lindfors

Subject: DP/IND/81/036 - Design Development of Concurrent Top and Bottom Blown Converter Steel Making - Contract No. 84/66

SUMMARY

Within the scope of the project expert studies on combined blowing technology, training of Indian engineers and pilot plant tests simulating Indian conditions were carried out.

The expert studies included process routes for combined blowing, design of a demonstration unit, process control studies and refractory technology.

A brief conclusion of the work done states the following:

- Regarding process routes the advantages with combined blowing under Indian conditions were studied and it is clear that combined blowing processes are suitable for Indian conditions. Thus the Indian idea to introduce the new technique by using permeable elements for inert gas inlet can be supported. In the future it is also advisable to do a pre treatment of the hot metal from the blast furnace to minimize the slag content in the converter.

- Regarding the design of a demonstration unit the work is based upon SAIL's proposal to rebuild one 100/130 ton converter at Bokaro plant. The design is done in such a way that a change from permeable bottom elements to tuyeres is foreseen and easy to accomplish.

  The work also covers our suggestion for the development of a 15 ton converter at Maharastra Electrosmelt Ltd. (MEL).

- Regarding process control the development of static control should improve production capacity in LD-furnaces, but the introduction calls for improvement on the instrumentation of the converters. The basic concept for the introduction of a dynamic process control based on MEFOS' system is also done. Such a system needs more instrumentation than a static system, for example a reliable computer and an off gas analyser. It has proven to give very accurate results.

- Regarding refractory technology economic considerations for the combined blowing technique are done showing that there are different opinions regarding life length of bricks if vessel capacity is adequate or not. Practices from Japan, Europe and Scandinavia are reported and compared to Indian conditions. The work concludes with lines of development to achieve improved practice for BOF general practice, permeable elements, tuyere based technology, test and simulation systems and refractory lances for hot metal treatment.

- Regarding the training, 10 Indian engineers spent 8 weeks in Sweden at MEFOS and at Norsk Jernverk A/S in Norway. During part of the time another 6 engineers visited MEFOS and Norsk Jernverk A/S.

It is our belief that the training in applied metallurgy, process control, design and engineering as well as pilot plant work at MEFOS was fruitful for the participants.

All members of MEFOS' staff taking part as teachers and advisers highly appreciated the interest and activity during the different lessons and studies at MEFOS and the visited steelworks.

- Regarding the pilot plant tests 15 trials were conducted using permeable bottom elements, tuyeres for inert gas or tuyeres with the possibility of oxygen injection.

  The experimental results were very good and gave a good indication that combined blowing with permeable elements or tuyeres is an efficient way to produce steel from Indian raw materials. When the problems with a good lance-practice were solved most of the benefits with combined blowing were found to be:

  - lower oxygen content in the steel, better manganese yield, better yield for alloying elements
  - lower iron content in the slag and better iron yield
  - good dephosphorization
  - less slopping an sculling.

Finally we can add that concurrent top and bottom blowing in converters is a technology that is well suited for Indian conditions. The choice to start the introduction of the technique using permeable elements with the possibility to change to tuyeres is supported.

Appendix 1

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SUBJECT: DP/IND/036 - CONTRACT NO 84/66 - EXPERT STUDIES

1. PROCESS ROUTES

by

Pekka Kuusela

Postadress
MEFOS
Box 812
951 28 Lulea

Telefon
0920-556 40

Telex
80482 MEFOS S

Bankgiro
758-6555

Postgiro
6 18 00-9

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1.1 ADVANTAGES WITH COMBINED BLOWING

When changing from traditional LD to combined blowing many metallugical benefits can be gained, e.g.:

- higher iron yield, lower FeO in the slag
- better sulphur removal
- slightly better phosphorous removal
- lower oxygen content in the steel
- better yield of alloying elements
- higher manganese-yield
- longer life of refractories
- lower consumption of lime
- less slopping and spitting
- less sculling
- larger scrap pieces can be used due to better mixing
- steel with very low carbon content can easily be produced

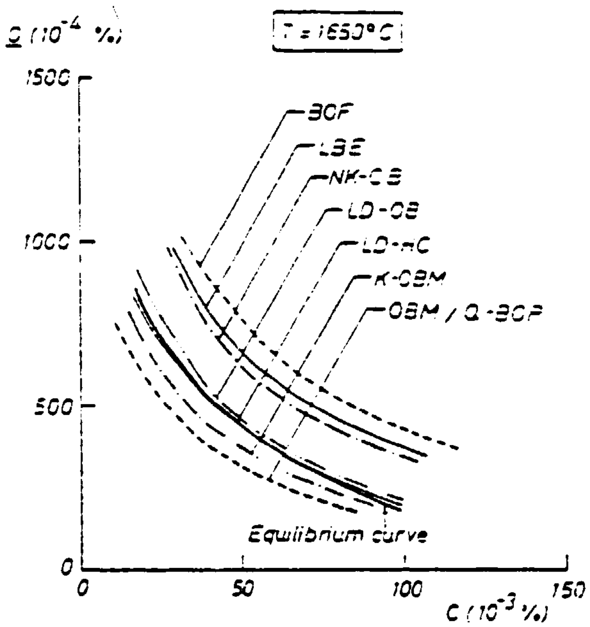
Combined blowing also has some disadvantages, such as:

- erosion in the bottom of the converter
- lower scrap-melting capacity
- higher N-content in the steel
- higher H-content in the steel

In the following pages both advantages and disadvantages of the combined blowing will be discussed.

1.1.1 Higher iron yield

In the LD-process the charge is always overoxidized, which means that a lot of iron is oxidized. In combined blowing one is working closer to the equilibrium, and this means that less iron is being oxidized. Equilibrium-curves CxO for some steelmaking processes are shown in Figure 1.



Carbon-oxygen relationships for several combined blowing processes.

Figure 1 - CxO-curves for some steelmaking processes /1/.

As shown in figure 1 the oxidation of the bath is lower in all combined blowing processes compared with conventional LD and the blowing is done closer to the equilibrium-curve, but coming beneath it only in K-BOP (K-OBM). The lowest oxidation is in the OBM (Q-BOP)-process.

When working close to the equilibrium it means that the charge is not overoxidized and that is why iron loss to the slag is lower. That means that the iron yield is increasing by 0.5-2.0% depending on which process is being used. Figure 2 shows the iron content in the slag as a function of the carbon content in the bath.

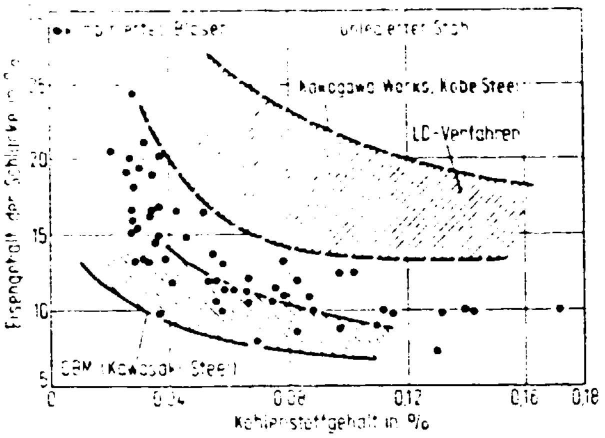


Figure 2 - Iron content in the slag as a function of the carbon content in the bath /2/.

As shown in Figure 2, the OBM-process has the lowest Fe-content in the slag at all carbon contents in the bath. Combined blowing shows a little higher Fe-content, although much lower than traditional LD-process.

1.1.2 Better sulphur removal

The mixing in the bath is much more effective in combined blowing than in the LD-process. This brings the slag forming agents in better "contact" with the metal bath and that is why the desulphurization effect of the slag is better. In Figure 3 the sulphur distribution between the slag and metal in different types of steelmaking process is shown as a function of slag basicity.

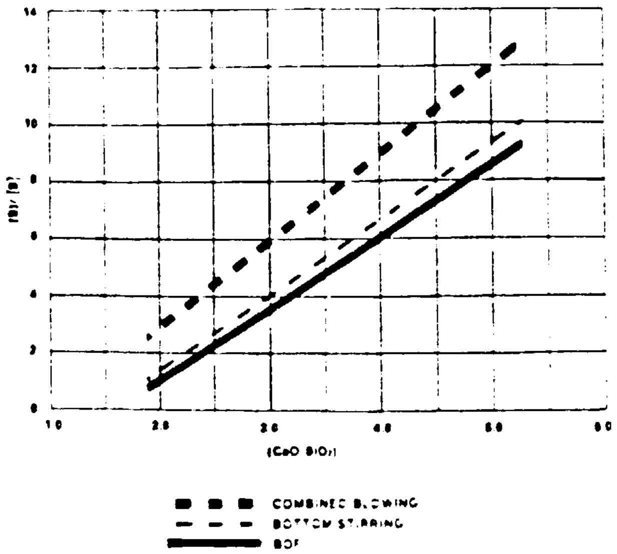


Figure 3 - Sulphur distribution vs. slag basicity CaO/SiO_2 /3/.

As shown in Figure 3, the sulphur distribution is lowest in normal LD, sligthly better in LD with bottom stirring and best in combined blowing. The sulphur distribution in combined blowing can be increased by injection of lime-powder or some lime-based material. This will be discussed later.

1.1.3 Phosphorous removal

Dephosphorization in combined blowing is slightly better compared with normal LD. The reason is the same as above, i.e. better mixing and better "contact" between the slag and metal. Figure 4 shows the phosphorous removal in different kind of steelmaking processes.

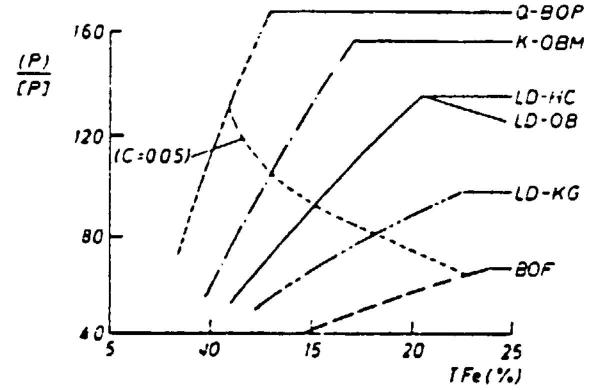


Figure 4 - Phosphorous distribution as a function of iron content in the slag /1/.

As shown in Figure 4, the iron content in the slag in normal LD must be increased in order to achieve the same phosphorous level in the steel as with combined blowing.

1.1.4 Lower oxygen content in the steel

With combined blowing the blowing is done closer to the equilibrium and consequently the bath is not overoxidized. This is the reason why the oxygen content in the steel is much lower than in normal LD. In Figure 5 the oxygen content in the steel is shown as a function of the carbon content in the steel.

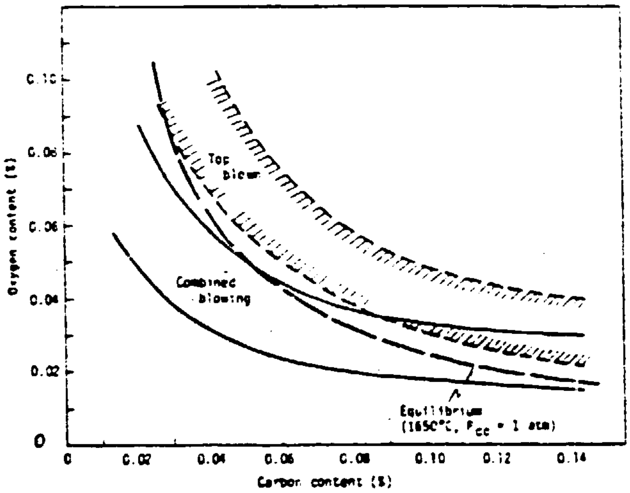


Figure 5 - Oxygen content in the steel vs. carbon content /4/.

As shown in Figure 5, the oxygen content in the steel is close to the equlibrium-curve CxO=0.0205 (T=1650°C, p=1 atm) and always much lower than in normal LD-process, where CxO=0.040 at the same temperature.

1.1.5 Higher manganese yield

In combined blowing overoxidation of the charges is avoided and consequently more manganese stays in the bath. Figure 6 shows the residual manganese content in the steel as a function of the final carbon content in the steel in different steelmaking processes.

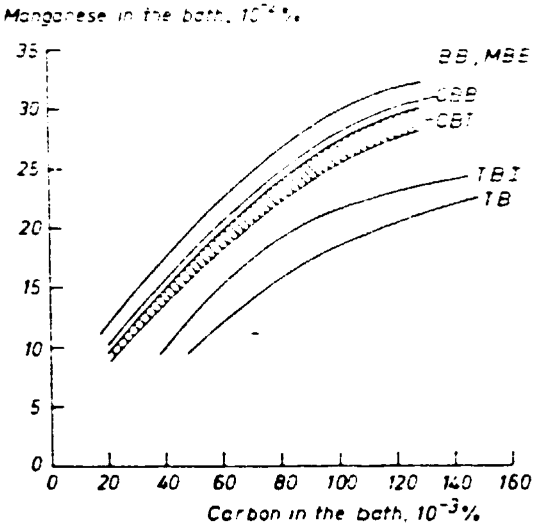


Figure 6 - Manganese content at turn-down /5/.

As shown in Figure 6, the residual manganese content in the steel is lowest in normal LD and highest in the OBM-process. Combined blowing processes are between these two.

1.1.6 Better yield for alloying elements

The yield of alloying elements is also higher in combined blowing compared with conventional LD. This is due to the fact that the oxygen content at turn-down is much lower. The affinity of alloying elements to oxygen is normally quite high, and when the oxygen content in the steel is lower, less alloying elements will be oxidized which means a higher yield of the elements. In Table I data for conventional LD, bottom purging and combined blowing is compared.

Table I - Consumption data for LD, bottom-stirring and combined blowing /3/.

TABLE I Anticipated consumption data per ton liquid steel for BOF, bottom stirring and combined blowing without post combustion

	Units	BOF	Bottom stirring	Combined blowing
Aim turndown—0.05% C, 0.025% S, 2950°F				
Hot metal[1]	lbs	1643.18 (71.91%)	1665.03 (73.60%)	1617.56 (72.82%)
Steel scrap[2]	lbs	641.83 (28.09%)	597.38 (26.40%)	603.73 (27.18%)
Burnt lime	lbs	147.33	151.03	127.39
Burnt dolomite	lbs	44.08	37.25	12.89
Fluorspar	lbs	5.00	2.00	—
Oxygen	scf	1868.60	1821.28	1693.41
Air	scf	—	10.39	209.06
Natural gas	scf	—	—	45.16
Nitrogen	scf	—	60.25	182.67
Argon	scf	—	15.32	15.22
HC FeMn, aim 0.50%	lbs	14.41	13.63	11.13
Al, aim 0.05%	lbs	3.70	3.45	3.22
Yield[3]	%	87.52	88.40	90.04
Aim turndown—0.15% C, 0.025% S, 2930°F				
Hot metal[1]	lbs	1692.34 (74.19%)	1710.15 (75.66%)	1660.31 (74.71%)
Steel scrap[2]	lbs	588.78 (25.81%)	550.11 (24.34%)	562.17 (25.29%)
Burnt lime	lbs	185.48	185.35	149.26
Burnt dolomite	lbs	16.68	12.21	0.90
Fluorspar	lbs	12.50	9.50	7.50
Oxygen	scf	1810.44	1769.18	1650.88
Air	scf	—	13.37	225.29
Natural gas	scf	—	—	44.03
Nitrogen	scf	—	58.43	182.67
Argon	scf	—	15.32	15.22
HC FeMn, aim 0.75%	lbs	21.19	20.19	16.70
Al, aim 0.05%	lbs	2.86	2.78	2.70
Yield[3]	%	87.68	88.49	89.99
Aim turndown—0.25% C, 0.025% S, 2920°F				
Hot metal[1]	lbs	1712.88 (75.07%)	1728.41 (76.41%)	1678.23 (75.44%)
Steel scrap[2]	lbs	568.69 (24.93%)	533.50 (23.59%)	546.50 (24.56%)
Burnt lime	lbs	202.88	200.65	152.30
Burnt dolomite	lbs	3.23	—	—
Fluorspar	lbs	17.50	14.50	12.50
Oxygen	scf	1771.60	1732.95	1616.24
Air	scf	—	14.94	233.41
Natural gas	scf	—	—	43.10
Nitrogen	scf	—	57.16	182.67
Argon	scf	—	15.32	15.22
HC FeMn, aim 1.00%	lbs	26.37	25.44	21.76
Al, aim 0.05%	lbs	2.38	2.32	2.27
Yield[3]	%	87.66	88.42	89.90

[1] Hot metal: 4.28% C, 0.80% Mn, 0.050% S, 0.070% P, 1.00% Si.

[2] Scrap: 50 lb pit scrap, 100 lb home scrap, balance No. 1 heavy melting (/ton of liquid steel).

[3] Yield: liquid steel/(hot metal + scrap).

As shown in Table 1, the amount of FeMn and Al needed is low with combined blowing and cost savings can be made.

1.1.7 Longer refractory life

Erosion of refractories is decreasing because of lower FeO-content in the slag. At the same time the erosion in the bottom of the converter can increase because of gas bubbling or injection of material through the bottom. These problems can be solved with a good slagging-in-practice of the bottom and with better brick-quality for the bottom. Figure 7 shows the life of refractories as a function of the iron-content in the slag.

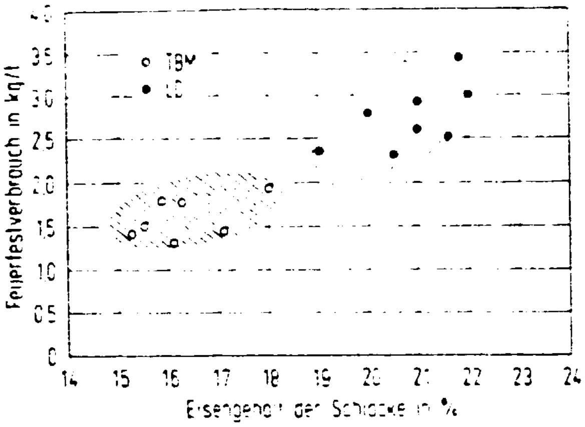


Figure 7 - Erosion of refractories (kg/ton steel) as a function of iron content in the slag /6/.

As shown in Figure 7, the consumption of refractories decreases with approx. 1,0 kg/ton steel when combined blowing is used instead of conventional LD-process.

Figure 8 shows the reduction in the iron content in the slag when changing from LD to combined blowing at the same plant.

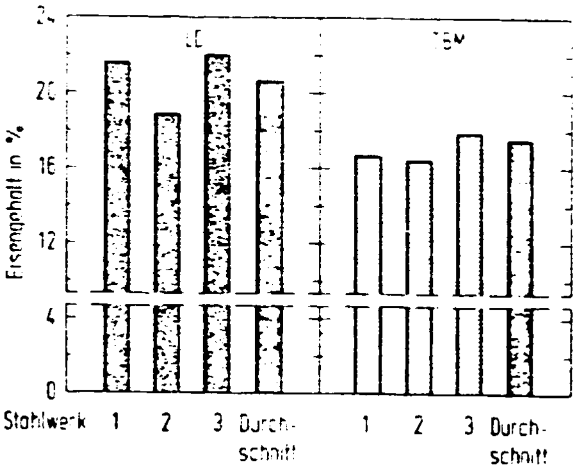


Figure 8 - Reduction of the iron content in the slag /6/.

1.1.8 Lower lime consumption

Lime consumption decreases in combined blowing compared with normal LD. The reason for this is better mixing and hereby the lime is in better "contact" with the metal. That is why the lime-input per ton of hot metal can be decreased. In Table II some interesting data from two steelworks with LBE-process is shown.

Table II - Reduction in material consumption with LBE /7/.

		Solmer	Usinor-Dunkerque
Changes in converter			
Lime	(kg/t)	-3	+4.5
Dolomite	(kg/t)	-8	-18
Iron Yield	(%)	+0.6	+0.5
Total	(FF/t)	-5.4	-6.2
Al	(kg/t)	-0.1	-0.3
LCFeMn	(kg/t)	-0.45	+0.3
HCFeMn	(kg/t)	-0.2	-0.7
Carbon	(kg/t)	0	0
Total	(FF/t)	-4.8	-4.1
Ar	(m^3/t)	0.11	0.18
N_2	(m^3/t)	1.56-	1.45
Total	(FF/T)	+1.5	+1.4
Total gains	(FF/t)	8.7	8.9

As shown in Table II, these two steelworks decreased their lime-consumption with approx. 5.0 kg/ton steel when changing from LD to combined blowing (LBE).

1.1.9 Less slopping and spitting

Good mixing prevents the formation of local oxygen-gradients which is the main reason for slopping and spitting. In Figure 9 the effect of mixing to slopping is shown.

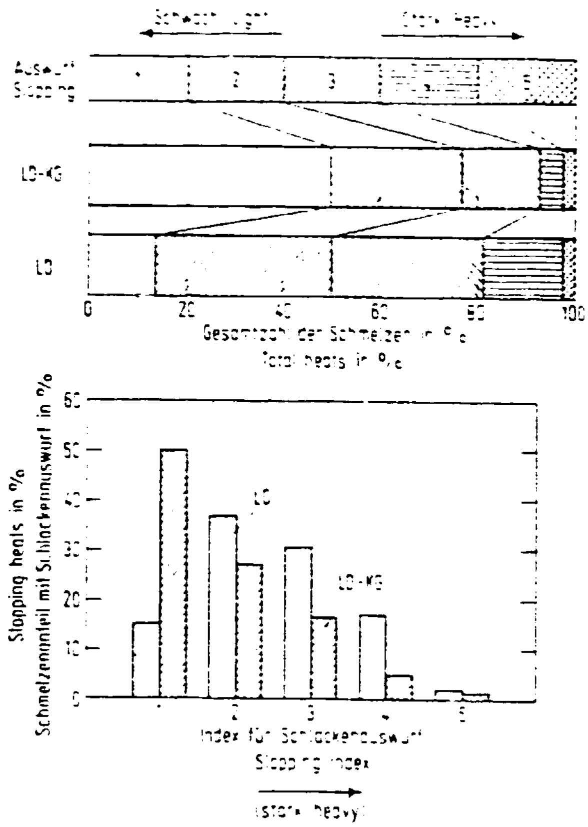


Figure 9 - Influence of mixing on the slopping /8/.

As shown in Figure 9, the slopping index decreases quite drastically when introducing combined blowing.

The same is shown in Figure 10, where comparison between conventional LD and bottom-stirring is made.

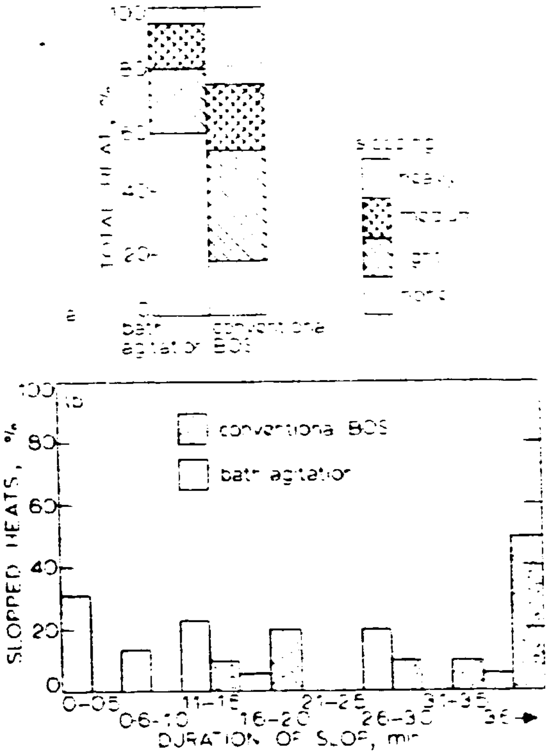


Figure 10 - Slopping data for LD and bottom stirring /9/.

Because of less slopping and better lime-yield stirring problems are decreased in combined blowing compared with LD-process.

1.1.10 Larger and cheaper scrap can be used

The mixing is quite good during blowing in combined-blown converter compared with LD-converter. That is why the scrap-melting velocity is higher, which is also shown in Figure 11.

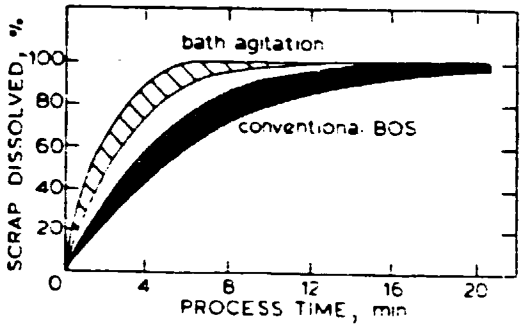


Figure 11 - Scrap-melting velocity /9/.

Also the mixing time is shorter in combined blowing, see Figure 12.

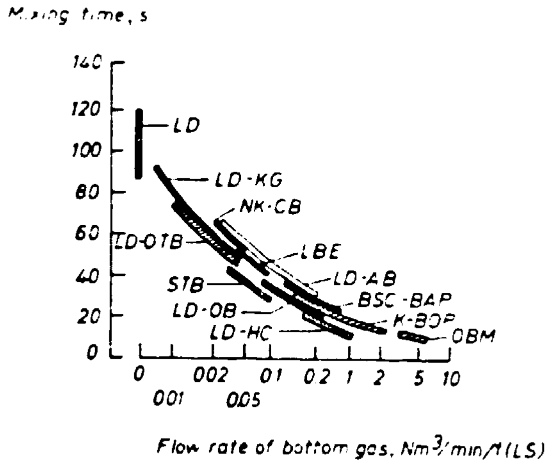


Figure 12 - Mixing time in some steelmaking processes /10/.

The mixing time in normal LD is about 90-120 seconds, in combined blowing, depending on the bottom-gas flow-rate, between 10-80 seconds and in a OBM-converter about 10 seconds. For these reasons, larger and cheaper scrap can be used in the converter. The scrap-melting capacity is, however, lower in combined blowing than in conventional LD (approx. 5-10 kg scrap/ton HM) because of the cooling effect of the inert bottom gas. Scrap-melting capacity can be increased by oxygen-injection through the bottom. Figure 13 shows the scrap-melting capacity as a function of the oxygen amount through the bottom in LD-HC-process.

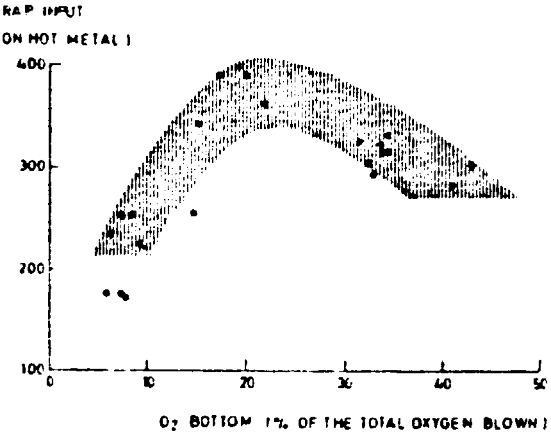


Figure 13 - Scrap-melting capacity as a function of percentage of oxygen through the bottom /5/.

As shown in Figure 13, the scrap-melting capacity is increasing when the percentage of oxygen through the bottom is increased, but the highest scrap-melting capacity is achieved at about 20% of the total oxygen going through the bottom and after that the scrap-melting capacity decreases in spite of increasing percentage of oxygen through the bottom.

1.1.11 Steel with very low carbon content can be produced

With combined blowing, steels with very low carbon content can easily be produced. The bottom-gas decreases the partial pressure of CO in the bath, therefore the carbon content in the bath can be decreased more effectively. With post-stirring, the partial pressure of CO can be decreased further, as shown in Figure 14.

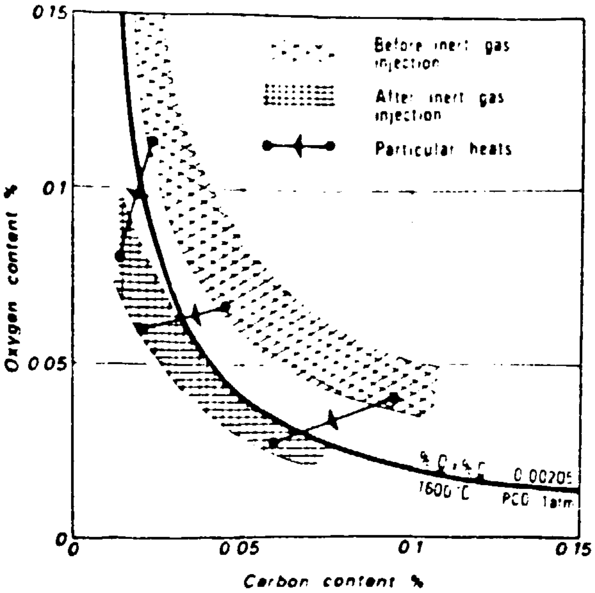


Figure 14 - Effect of post-stirring on the C- and O-content of the steel /11/.

In Table III, a comparison between LD and LBE-process when producing steel with very low carbon content (<0.020%) is done.

Table III - Comparison between LD- and LBE-process when producing steels with very low carbon contents /12/.

Metallurgical comparison of LBE and LD process for the production of very low carbon steels. C ≈ 0.02%

USINOR, Denain works 65-tonne LD converter

Tap conditions	Conventional LD	LBE process Before Injection	LBE process After Injection	Difference LBE-LD
Composition, %:				
C	0.02	0.05	0.02	0
O	0.14	0.06	0.06	−0.08
Mn	0.08	0.170	0.145	+0.065
P	0.013	0.011	0.008	−0.005
S	0.014	0.014	0.012	−0.002
N	0.0024	0.0022	0.0029	+0.0005
Slag Fe, %	35	18	19	−16
Nitrogen consumption, cu metres/tonne	—	—	1	+1

As shown in Table III, it is possible to produce steel qualities with a small iron loss (ΔFe_{slag} = 16%) with the LBE-process and at the same time reach a high manganese yield and low P- and S-contents in the steel. The only disadvantage with LBE-process is the N-content which is 5 ppm higher than in conventional LD.

It can also be mentioned that steel qualities with carbon contents less than 0.010% have been produced with combined blowing.

1.2 DISADVANTAGES WITH COMBINED BLOWING

1.2.1 Erosion in the bottom

Gas- and material-injection through the bottom causes high erosion of the bottom bricks. This has caused a lot of problems. In Figure 15 the influence of post-stirring to the erosion of bottom-bricks is shown.

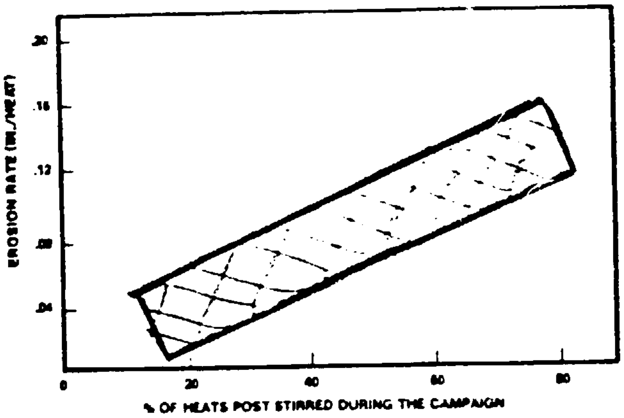


Figure 15 - Effect of post-stirring on refractory erosion /13/.

The quality of bottom-bricks and permeable elements has been much developed; permeable elements with high carbon content are the best in current use. Also the right slagging-in-practice for the converter has been developed, and that is why the life of the bottom has increased and it can be said that the bottom-life in a combined-blown converter is as long as the life of other bricks in the converter.

1.2.2 Decreased scrap-melting capacity

Bottom-gases and injected materials have a cooling effect which decreases the scrap-melting capacity in a combined-blown converter a little. Different steelworks have reported a decrease in scrap-melting capacity by 2-10 kg/ton HM when combined-blowing has been introduced. Due to good mixing in the bath larger and cheaper scrap can be used. Post-combustion of CO in the converter and injection of coal or coal-based material into the converter in order to increase the scrap-melting capacity have been studied. Figure 16 shows one type of post-combustion lance and results achieved with it and with anthracite-addition from a bin above the converter.

		scrap (kg ton steel)
BOF 2 and 3	conventional blowing	252
BOF 1	combined blowing	240
	combined blowing and DO lance	263
	combined blowing and DO lance and 10 kg anthracite ton steel	295

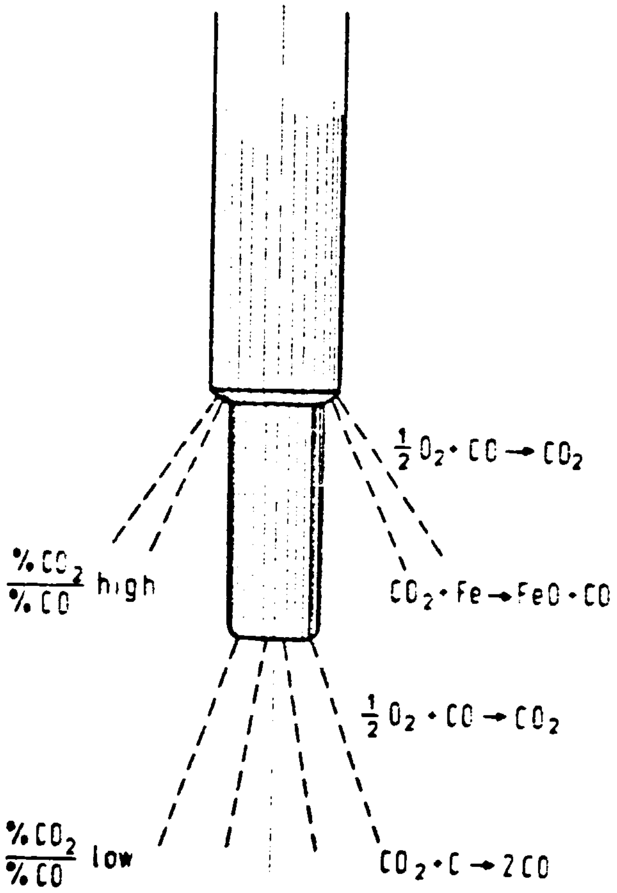

$\frac{1}{2}O_2 + CO \rightarrow CO_2$
$\frac{\%CO_2}{\%CO}$ high
$CO_2 + Fe \rightarrow FeO + CO$
$\frac{1}{2}O_2 + CO \rightarrow CO_2$
$\frac{\%CO_2}{\%CO}$ low
$CO_2 + C \rightarrow 2CO$

Figure 16 - Post-combustion lance and achieved scrap-melting capacity /14/.

In Table IV changes in scrap-melting capacity when introducing combined blowing in different steelworks are shown.

Table IV - Reported scrap-rates with combined-blowing /15/.

Summary of reported scrap rates using low phosphorus hot metal

Company	Process	Scrap rate compared with LD, kg/tonne of liquid steel
Hoogovens[6]	BSC	−8 to −17
Hoogovens[6]	BSC with post-combustion	+1 to +19
Stelco[7]	LBE	0
Jones & Laughlin[8]	—	−10
National Steel, Great Lakes[9]	Standard LBE	−11 to −16
National Steel, Great Lakes[9]	LBE with post-combustion	+11 to +27
USINOR, Dunkirk and Solmer[10]	LBE	0
Thyssen[11]	TBM	0
Krupp[12]	—	+10 to +18
Hoesch[13]	—	−13

1.2.3 Higher N-content in the steel

Bottom-injection of nitrogen causes higher nitrogen content in the steel. Normally, the N-content at turndown is some 10-20 ppm higher in combined blowing than in conventional LD-process. An attempt has been made to solve this problem by poststirring with argon, or at the final stage of blowing switching from nitrogen to argon. Figure 17 shows the reduction of nitrogen content in the steel as a function of the time when switching to argon at the end of the blowing.

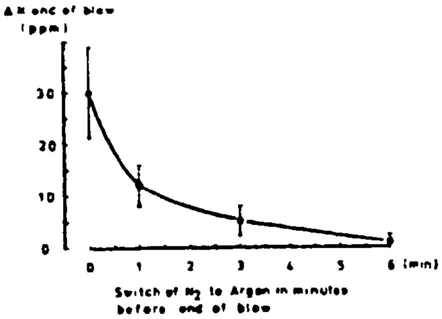


Figure 17 - Nitrogen pick-up at the end of the blow and argon stirring /14/.

1.2.4 Higher H-content in the steel

When tuyeres are used in combined blowing propane or natural gas is used for shielding them. This causes higher hydrogen-content in the steel. A solution to this is to use post-stirring with argon. Figure 18 shows a comparison between combined blowing and normal LD.

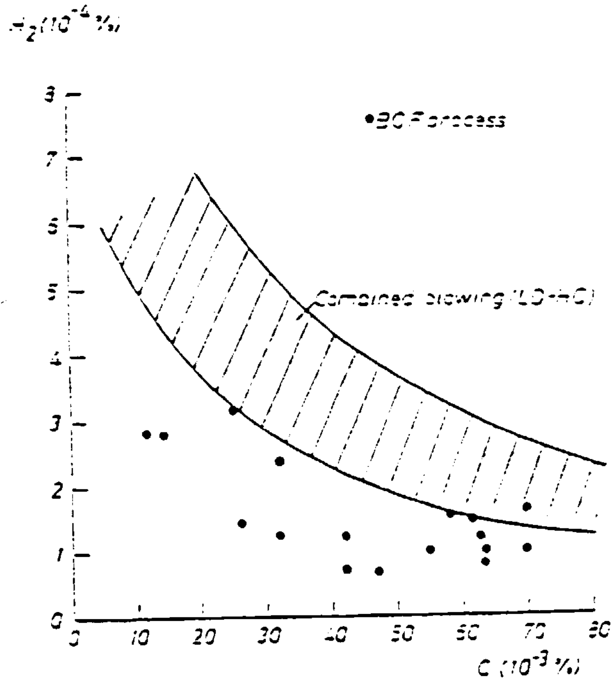


Fig. 11 - Hydrogen-carbon relationships at turndown.

Figure 18 - Hydrogen-carbon relationships at turndown /1/.

In Figure 19, the effect of post-stirring on the H-content in the steel is shown.

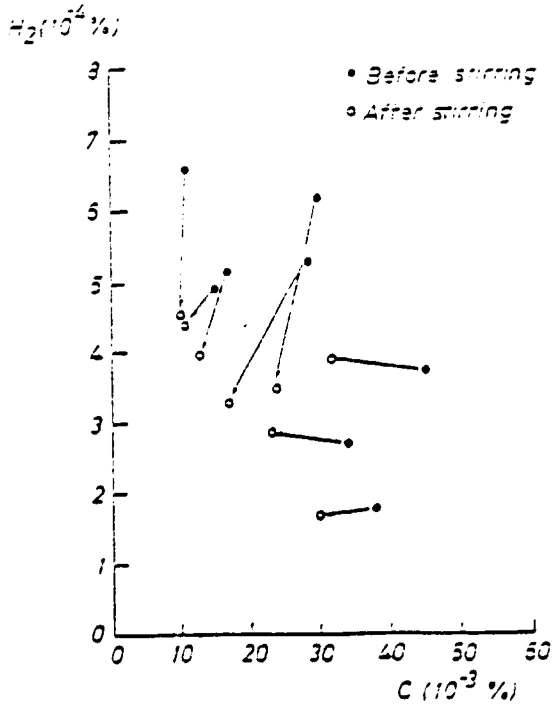


Figure 19 - Decrease of the hydrogen content during post-stirring /1/.

As shown in Figure 19, one minute of post-stirring decreases the hydrogen content in the steel with some ppm, achieving the same levels as in conventional LD-process.

1.3 COMBINED BLOWING - DESCRIPTION OF KNOWN PROCESSES

Different processes in combined blowing can be divided into four groups:

I	Inert gas through permeable elements
II	Inert gas through tuyeres
III	Reactive gas through tuyeres
IV	Reactive gas + lime through tuyeres

Tables V and VI give all-round data of different combined blowing processes; Table V advantages and disadvantages and Table VI flows of different gases and materials.

Table V - Combined blowing processes - advantages and disadvantages /4/.

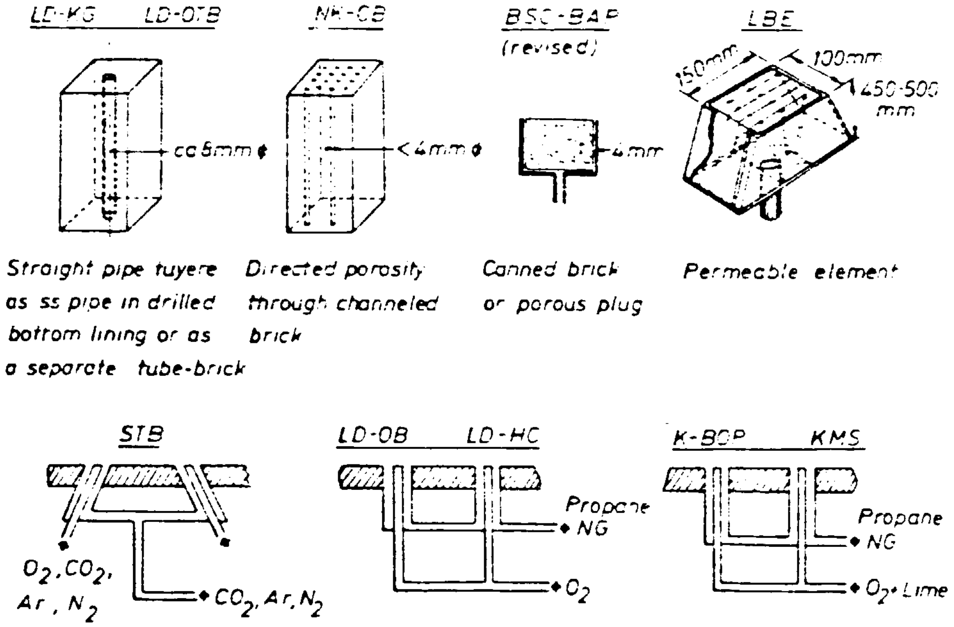
Comparison of Various Bottom Blowing Gases and Operating Techniques Used in the Combined Blowing Process

Bottom blowing gas	Bottom blowing method		Features		Process
			Advantages	Disadvantages	
Inert gas (Ar, N_2)	Porous or permeable bricks		• Low equipment costs • Low hydrogen content • Possible to interrupt the bottom blowing	• Ar gas cost (Ar) • Higher nitrogen content (N_2) • Little nitrogen increase by special blowing technique	LBE F.R. Germany
	Pipes		• Low equipment cost • Low hydrogen content	• Ar gas cost (Ar) • Higher nitrogen content (N_2)	LD-KG LD-AB LD-OTB F.R. Germany
Air (Air + N_2)	Annular tuyeres (N_2 cooling)		• Low equipment costs • Low hydrogen content • Low gas costs	• Higher nitrogen content	BAP
Carbon dioxide ($CO_2 + O_2$)	Annual tuyeres (CO_2 cooling)		• Recycling of recovered converter gas • Low hydrogen content	• Endothermic reaction $CO_2 + C = 2CO$ • CO_2 gas cost	STB
Oxygen (O_2+CmHn)	Without CaO powder	Annular tuyeres (CmHn cooling)	• Exothermic reaction $O_2 + 2C = 2CO$ • Bath agitation by CO bubbles	• Higher hydrogen content • Coolant cost • High equipment cost	LD-HC LD-OB LD-OTB NK-CB
	With CaO powder through the bottom		• Dittos as the above • Active lime powder injection	• Higher hydrogen content • Coolant cost • Lime powder producing cost • High equipment cost	KMS K-BOP

Table VI - Flows of different gases and materials in combined-blowing /4/.

LD-KG	Kawasaki Steel	100	3 0 3 5	0		Ar/N_2 at 0 01-0 05	L			Small-diameter tuyeres used for Ar/N_2 through bottom of converter
LBE	ARBED IRSID	100	4 0 4 5	0		Ar/N_2 at 0 0 25 (0 17 0 25 normal)	L			Permeable elements at converter bottom used to inject Ar/N_2
LD-OTB	Kobe Steel	100	3 3 3 5	0		Ar/N_2 at 0 01 0 10	L			Stirring pattern of inert gas through bottom varied
NK-CB	Nippon Kokan (NKK)	100	3 0 3 3	0		$Ar/CO_2/N_2$ at 0 04 0 10	L			Single-hole tuyeres or multihole plugs at converter bottom used to very inert gas flowrate
LD-AB	Nippon Steel	100	3 5 4 0	0		Ar at 0 014 0 310	L			Tuyeres at converter bottom used for injecting argon
J&L system	Jones and Laughlin	100	3 3 3 5	0		$Ar/N_2/CO_2$ at 0 045 or 0 112	L			Bottom tuyeres or channelled bricks to inject N_2 for most of blow and Ar/CO_2 in last stages
BSC-BAP	BSC (Teesside Lab.)	85-95	2 2-3 0	5-15 (as air)		Ar 0 075-0 200; N_2 0 035 0 050	L			Bottom oxygen through tuyeres/bricks as air shrouded by nitrogen
LD-OB	Nippon Steel	80-90	2 5-3 0	10 20	0 3 0 8	Natural gas to shroud bottom tuyeres	L			OBM-type tuyeres at bottom shrouded by natural gas
LD HC	Hainaut-Sambre-CRM	92 95	3 1-4 2	5 8	0 08 0 20	Natural gas to shroud bottom tuyeres	L or P			Tried in earlier LD AC shops with facilities for top addition of powdered lime/lump lime
STB and STB-P	Sumitomo Metals	90-92	2 0-2 5	8 10	0 15 0 25	Inner tuyere O_2/CO_2; outer tuyere $CO_2/N_2/Ar$ at 0 03 0 07	L or P (in STB P)			Very flexible tuyere system at bottom to introduce oxidizing gas. In STB-P, powdered lime is blown into hot spot from top
K BOP	Kawasaki Steel	60-80	2 0 2 5	20 40	0 7 1 5	Natural gas to shroud bottom tuyeres		P		Lime injected from bottom with some oxygen in OBM-type tuyeres
OBM	Maxhütte-US Steel	0		100	4 5 5 0	Natural gas to shroud bottom tuyeres		P		Hydrocarbon fluid used to shroud tuyeres
OBM-S	Maxhütte-Klöckner	20 40		60-80		Natural gas to shroud bottom and side tuyere		P		Top oxygen through shrouded side tuyere Sometimes coupled with gas/oil preheating of scrap Extra oxygen used 5 Nm^3/t of steel and scrap increased by 60 kg/t of liquid steel
KMS-KS	Klöckner-Maxhütte	0		100	4 5-5 0	Natural gas to shroud bottom tuyeres		P	(i) oil instead of natural gas through bottom tuyere along with O_2 at first and later changed to conventional OBM system (ii) injection of anthracite along with bottom oxygen during blow	Called KS if 100% scrap is used (i) 15-20% more scrap can be consumed (ii) physically 50 55 kg of coal injected per tonne of steel to increase scrap rate by 18-20% along with 40 45 $Nm^3 t^{-1}$ more oxygen + lime, etc
Hoogovens-BSC	Hoogovens-BSC	100	3 33			N_2/Ar 0 04-0 10	L		(i) secondary O_2 supply (ii) secondary O_2 + 10 kg anthracite addition	Annular nozzles used earlier, later canned bricks with (i) scrap increase 3-5 kg t^{-1}, (ii) scrap increase 30 kg t^{-1}
ALCI	ARBED	100	4 0-4 5	0		Ar/N_2 at 0 0 25 (0 17-0 25 normal)	L		Increased blowing time and increased oxygen or else anthracite injected from top	Same as LEB but to increase scrap consumption by about 50 kg/t of liquid steel, a special double flow lance can be used to improve post-combustion or further increase possible by coal injection from the top - 7 kg scrap increase per kg of pure carbon injected

Figure 20 describes different tuyeres and permeable elements and different types of bottom-injection (both gases and material).


LD-KG
LD-OTB
NK-CB
BSC-BAP
(revised)
LBE
ca 6mm ϕ
<4mm ϕ
4mm
150mm
100mm
450-500 mm
STB
O_2, CO_2, Ar, N_2
CO_2, Ar, N_2
LD-OB
LD-HC
Propane
+ NG
+ O_2
K-BOP
KMS
Propane
+ NG
+ O_2 + Lime

Straight pipe tuyere as ss pipe in drilled bottom lining or as a separate tube-brick

Directed porosity through channeled brick

Canned brick or porous plug

Permeable element

Schematic representation of methods used for bottom injection in hybrid processes

Figure 20 - Bottom-injection in combined-blowing /10/.

Figure 21 shows the bottom-gas flows in different steelmaking processes and Figure 22 the amount of gas injected through the bottom in different combined-blowing processes.

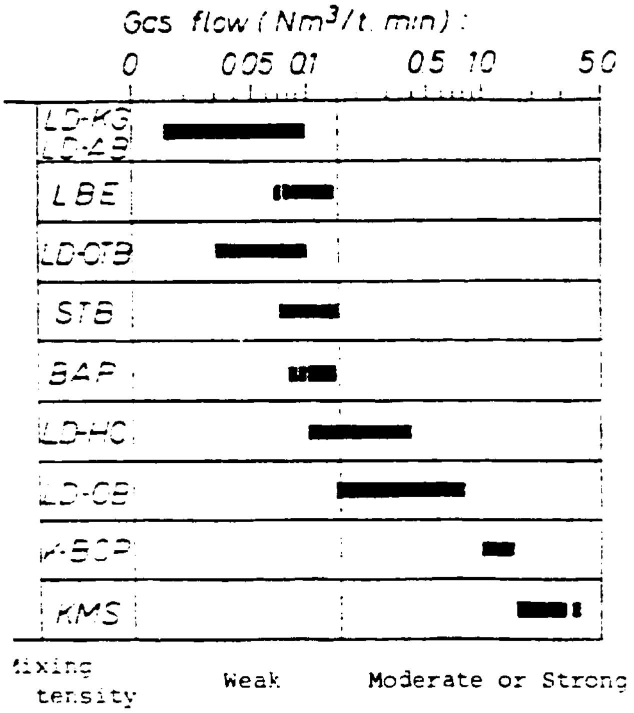
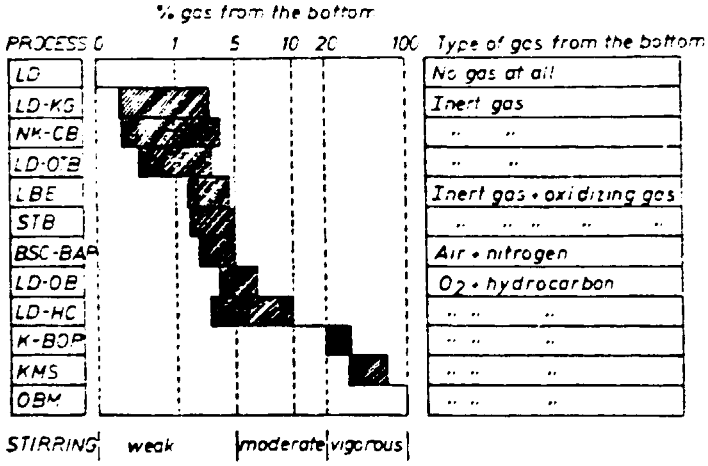


Figure 21 - Examples of combined blowing /5/.



Oxygen-steelmaking processes and type and percentage of basal gas

Figure 22 - Combined-blowing - bottom gas /10/.

3.1.1 Inert gas through permeable elements

LBE-process (Lance-Bubbling-Equilibrium)

LBE is the most common combined blowing process. Currently there are more than 50 converters in the world using the LBE-system. In Figure 23 a LBE-converter is shown.

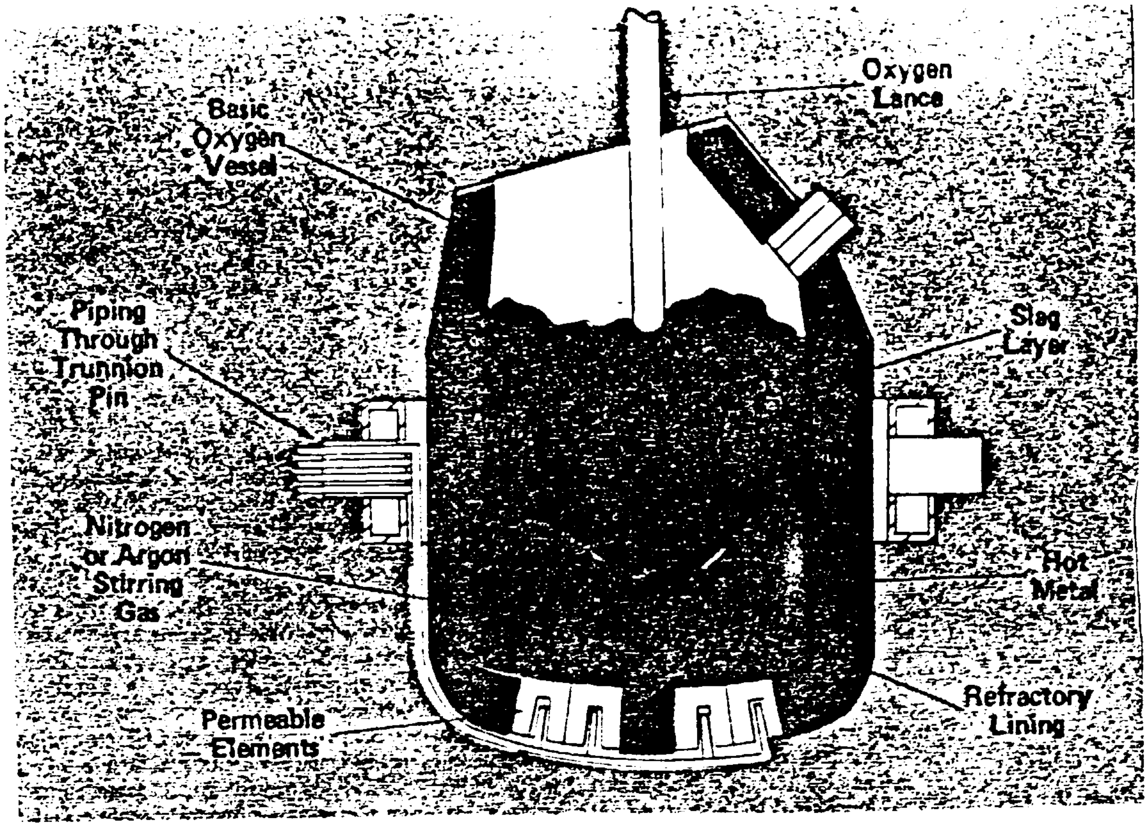

Oxygen Lance
Basic Oxygen Vessel
Piping Through Trunnion Pin
Slag Layer
Nitrogen or Argon Stirring Gas
Hot Metal
Refractory Lining
Permeable Elements

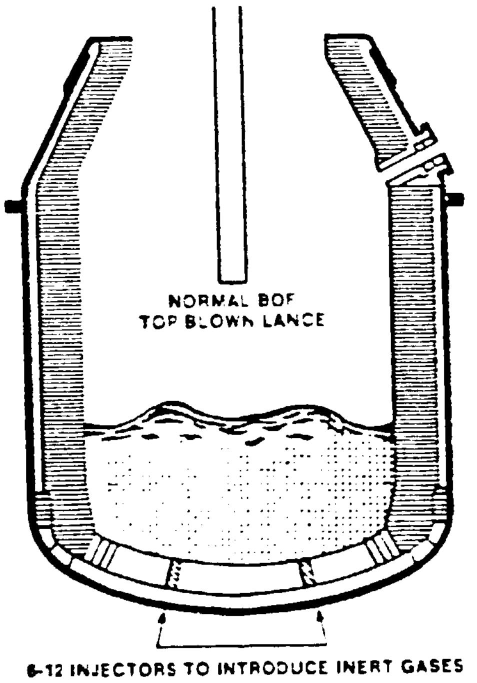
Figure 23 - LBE-converter /16/.

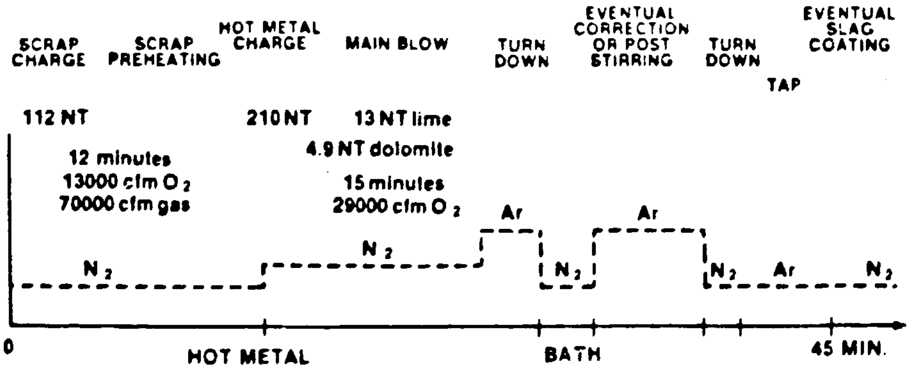
In the LBE-process nitrogen is mostly used during the blowing and at the end of blowing it is swithced to argon or the charge is post-stirred with argon depending on the quality of steel produced.

Jones and Lauglin-process

This process uses permeable elements or tuyeres. Nitrogen, argon or CO_2 is purged depending on the steel quality produced. Figure 24 shows a Jones & Lauglin-converter and blowing-practice for low-carbon steel.

Fig 1 — Cross-section of a 285-ton BOF at Indiana Harbor works equipped with bottom stirring


NORMAL BOF
TOP BLOWN LANCE
6-12 INJECTORS TO INTRODUCE INERT GASES



HOT METAL	
C	4.4%
P	0.08
Si	1.0
Mn	1.0
S	0.015
T°	2450° F

BATH	
C	0.043%
P	0.006
Mn	0.190
S	0.017
T°	2920° F
O	300 ppm

Figure 24 - Jones & Lauglin-converter and the blowing program /13/.

Krupp-system

Krupp uses both permeable elements and tuyeres. Nitrogen and argon are used as bottom-gas. In Figure 25 a description of Krupp-converters is given.

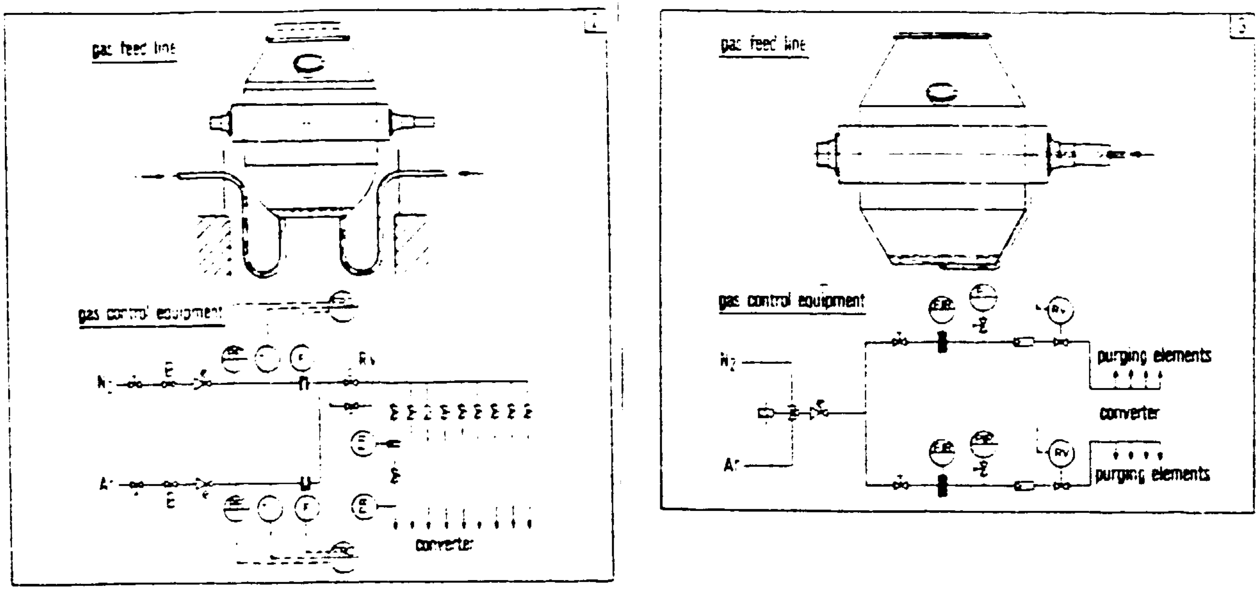

gas feed line
gas control equipment
N_2
Ar
converter
gas feed line
gas control equipment
N_2
purging elements
converter
Ar
purging elements

Figure 25 - Krupp-converters /17/.

BSC-Hogoovens-process

In the BSC-Hogoovens-system permeable elements are used in the bottom of the converter. They have started to use post-combustion of CO and anthrasite-additions from a bin in order to increase the scrap-melting capacity. Figure 26 shows the BSC-Hogoovens-system.

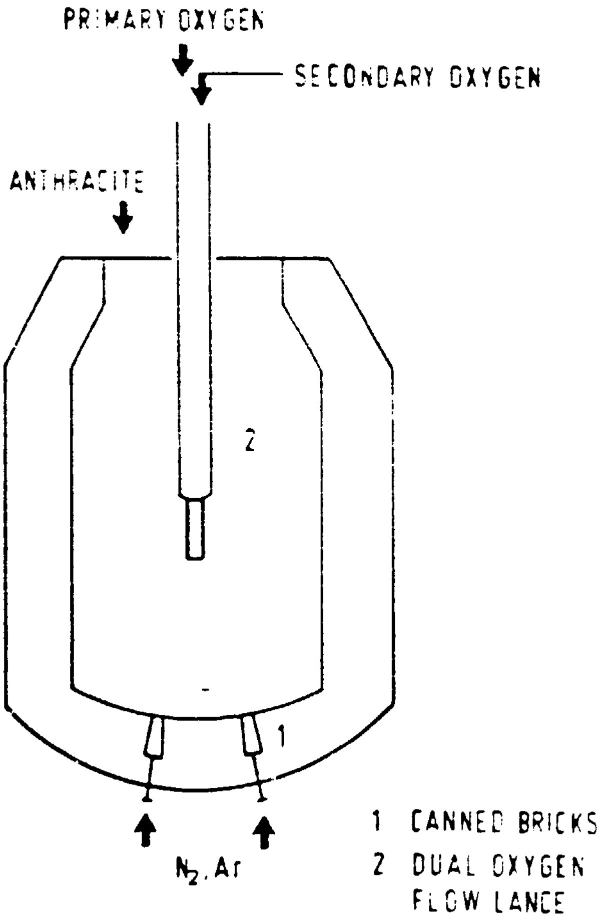

PRIMARY OXYGEN
SECONDARY OXYGEN
ANTHRACITE
2
1
N_2, Ar
1 CANNED BRICKS
2 DUAL OXYGEN FLOW LANCE

Figure 26 - BSC-Hogoovens-system /14/.

MEFOS-system

MEFOS-system is completely flexible. Both permeable elements and tuyeres can be used. Nitrogen or argon are used as bottom-gas. Figure 27 shows the MEFOS-system.

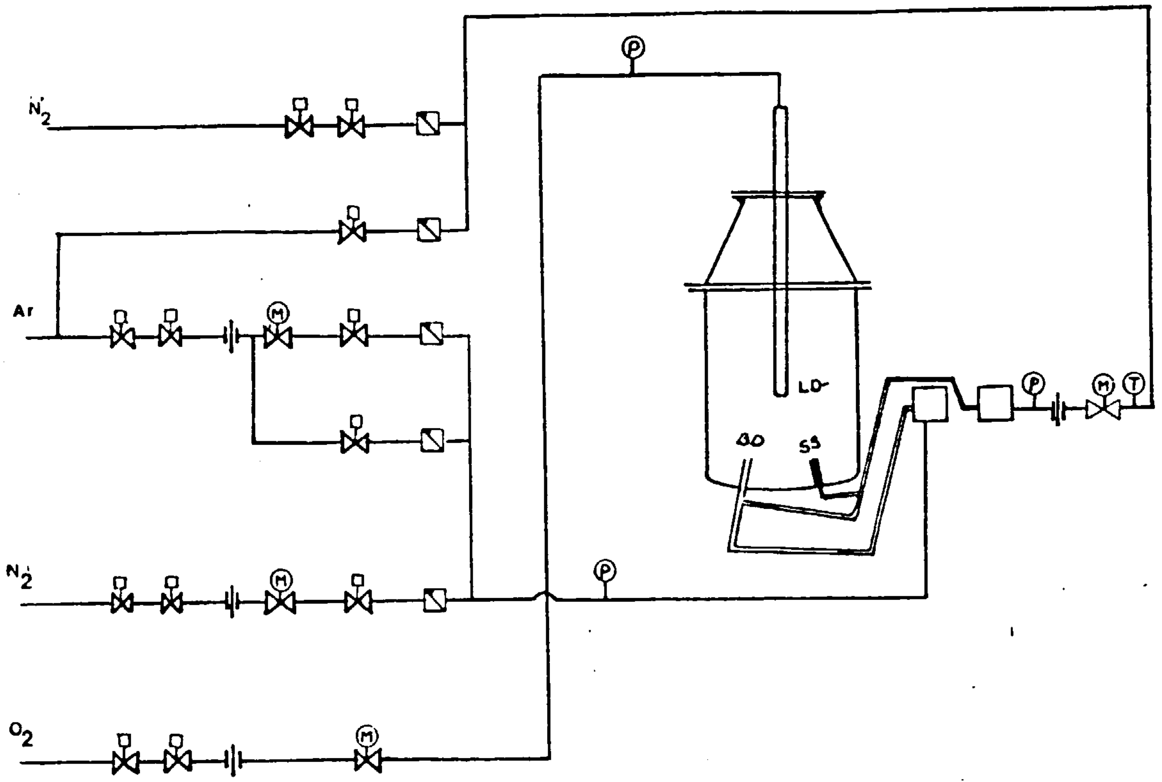


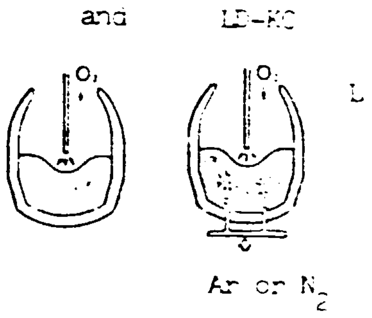
Figure 27 - MEFOS-system.
LD-SS = Permeables
LD-BD = Tuyeres

1.3.2 Inert gas through tuyeres

When using tuyeres instead of permeable elements a more flexible system is given and higher pressures can also be used.

LD-KG-system (LD-Kawasaki-Gas)

In the LD-KG-system nitrogen and argon are used as bottom-gas. Figure 28 shows a LD-KG-converter.



Comparative features of LD and LD-KG
Ar or N_2

Figure 28 - LD-KG-converter /18/.

LD-AB-system (LD-Argon Bottom)

In the LD-AB-system argon is used as bottom-gas during the whole blowing period. It is not so popular now because of the high cost of gas.

LD-OTB-process (LD-Oxygen Top and Bottom)

The LD-OTB-process is used in two different variants. In the first one N_2, Ar and CO_2 are used and in the second N_2, Ar and O_2 are used. Figure 29 shows a sketch of both variants with bottom-gas flow-rates for different steel qualities.

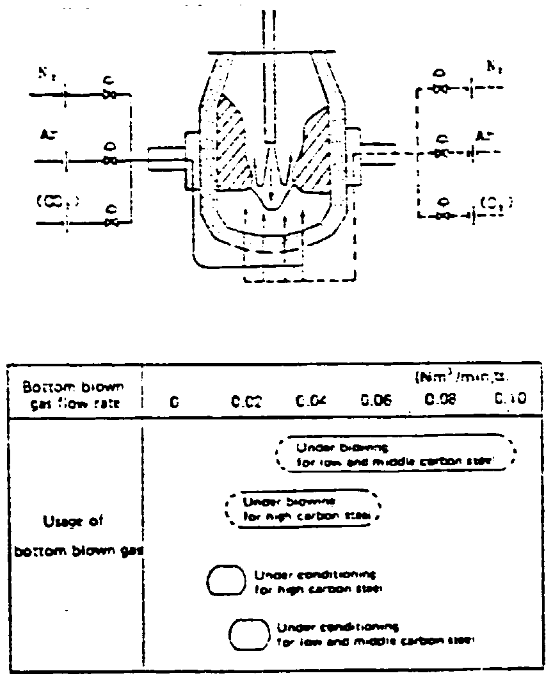

N₂
Ar
(CO₂)
N₂
Ar
(CO₂)
Bottom blown gas flow rate
(Nm³/min,t)
0
0.02
0.04
0.06
0.08
0.10
Usage of bottom blown gas
Under blowing for low and middle carbon steel
Under blowing for high carbon steel
Under conditioning for high carbon steel
Under conditioning for low and middle carbon steel

Figure 29 - LD-OTB-process and used gas flow-rates /19/.

NK-CB (Nippon Kokan - Combined Blowing)

In NK-CB-process N_2, Ar and CO_2 are used as bottom-gas. The NK-CB-system is shown in Figure 30.

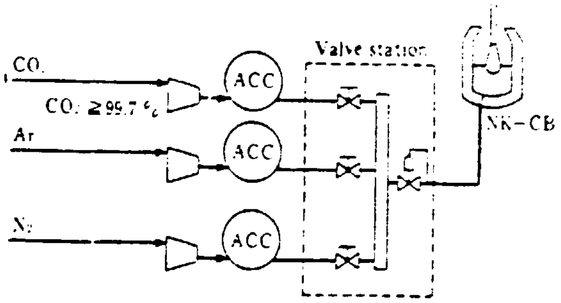

CO₂
CO₂ ≥ 99.7 %
Ar
N₂
ACC
ACC
ACC
Valve station
NK-CB

Figure 30 - NK-CB-process /20/.

1.3.3 Reactive gas (oxygen) through tuyeres

BSC-BAP-process (BSC-Bath Agitation Process)

In the BSC-BAP-process nitrogen, argon and air are used as bottom-gas. Nitrogen is used for cooling the tuyeres.

LD-OB-process (LD-Oxygen Bottom)

In the LD-OB-process OBM-tuyeres are used in the bottom of the converter. These tuyeres are shrouded with propane. As can be seen from Figure 31, oxygen, nitrogen, argon or air are used as bottom-gas.

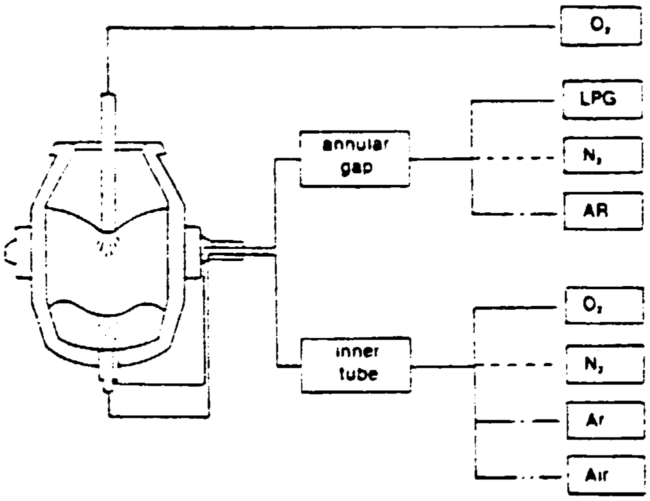


Figure 31 - LD-OB-process /21/.

LD-HC-process (LD-Hydrocarbon)

In the LD-HC-process oxygen is used as bottom-gas and propane for cooling the tuyeres. A sketch of the LD-HC-converter is shown in Figure 32.

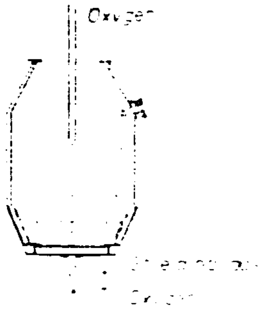


Figure 32 - LD-HC-process /22/.

STB- and STB-P-process (Sumitomo Top and Bottom)

In the STB-process oxygen or CO_2 are used as bottom-gas and N_2, Ar or CO_2 are used for cooling the tuyeres. Figure 33 shows a STB-converter.

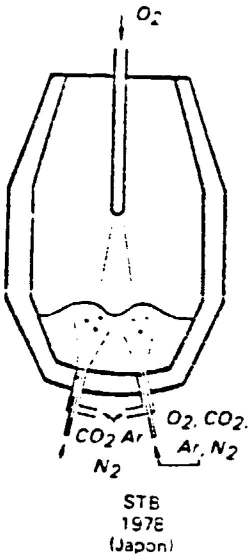

O_2
CO_2 Ar
N_2
O_2, CO_2,
Ar, N_2
STB
1978
(Japon)

Figure 33 - STB-converter.

In the STB-P-process pulverized lime is injected from the top, in normal STB-process lime is added in lump form from a bin above the converter.

1.3.4 Oxygen + lime-injection through the tuyeres

K-BOP (Kawasaki-BOP)

In the K-BOP (K-OBM)-process, lime-powder is injected through the bottom. Propane is used for cooling the tuyeres. Nitrogen or argon can also be injected through the tuyeres. A K-BOP-converter is shown in Figure 34.

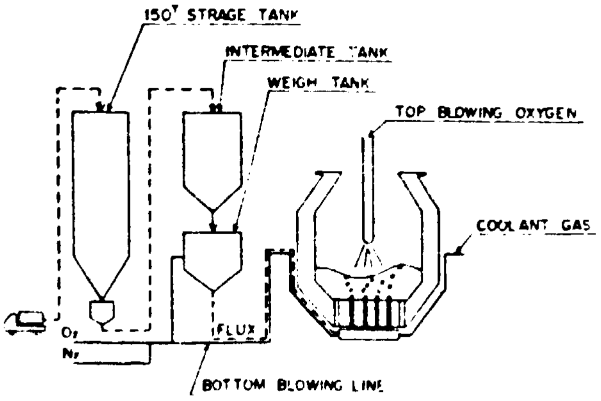
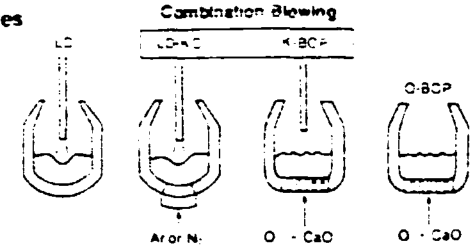

150T STRAGE TANK
INTERMEDIATE TANK
WEIGH TANK
TOP BLOWING OXYGEN
COOLANT GAS
O_2
N_2
FLUX
BOTTOM BLOWING LINE

Figure 34 - Lay-out of K-BOP-process /24/.

In Figure 35 data about LD, OBM and combined blowing and some advantages of K-BOP compared with traditional LD-praxis is shown.

Types of BOF and Comparative Features


Combination Blowing
LD
LD-KG
K-BOP
Q-BOP
Ar or N₂
O₂ · CaO
O₂ · CaO

Bottom Blowing Gas Volume	None	→	Large
Agitation	Weak	→	Strong
FeO in Slag	High	←	Low
Slopping	Large	←	None
Yield ratio	Low	→	High
Dephosphorization of high carbon steel	Suitable	←	Unsuitable
Dephosphorization of low carbon steel	Unsuitable	→	Suitable

Features of K-BOP

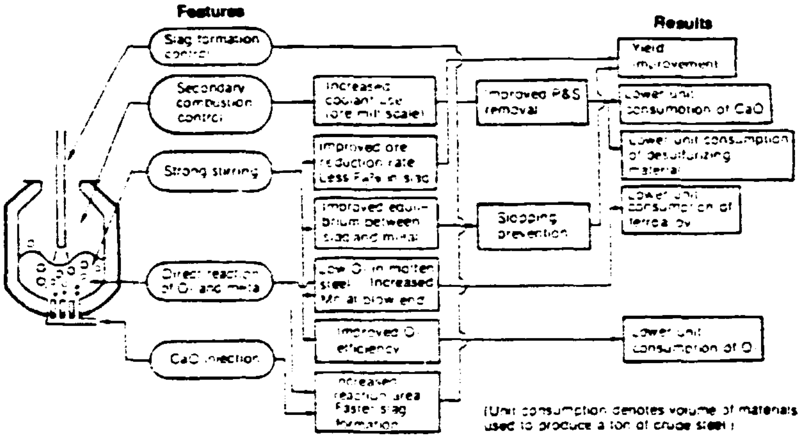

Features
Results
Slag formation control
Secondary combustion control
Strong stirring
Direct reaction of O₂ and metal
CaO injection
Increased coolant use (ore mill scale)
Improved ore reduction rate Less FeO in slag
Improved equilibrium between slag and metal
Low O₂ in molten steel Increased Mn at blow end
Improved O₂ efficiency
Increased reaction area Faster slag formation
Improved P&S removal
Slopping prevention
Yield improvement
Lower unit consumption of CaO
Lower unit consumption of desulfurizing material
Lower unit consumption of ferroalloy
Lower unit consumption of O₂
(Unit consumption denotes volume of materials used to produce a ton of crude steel.)

Figure 35 - Comparison K-BOP-LD /25/.

KMS-process, KS-process (Klöckner-Maxhütte)

In the KMS-process all known gases used in combined blowing are used. Through the bottom O_2, air, N_2 or Ar are injected, propane is used for cooling. Lime and fluxes are injected through the tuyeres and coal-powder can also be injected. In the latter case in order to increase the scrap-melting capacity. About 60% of the oxygen used in the process is injected through the bottom, the rest of O_2 through the lance or through side-tuyeres high up in the converter. A KMS-vessel with all possible gas-flows is shown in Figure 36.

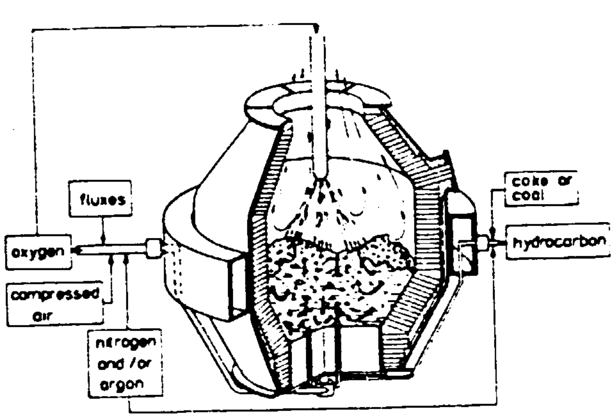

fluxes
oxygen
compressed air
nitrogen and /or argon
coke or coal
hydrocarbon

Figure 36 - KMS-process /26/.

Figure 37 shows the valve- and injection-system of a KMS-converter. KMS can also be charged with 100% of scrap, then it is called KS-process.

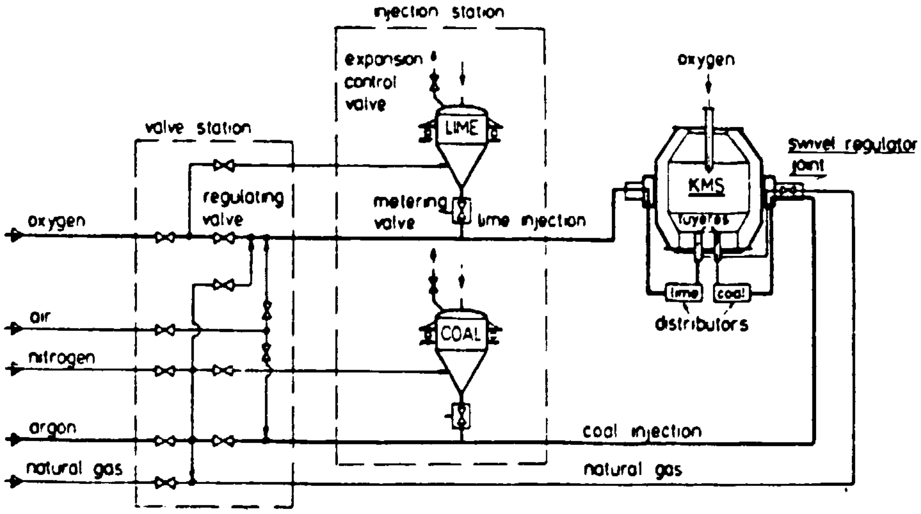

injection station
expansion control valve
LIME
metering valve
lime injection
valve station
regulating valve
oxygen
air
nitrogen
argon
natural gas
COAL
coal injection
natural gas
oxygen
swivel regulator joint
KMS
tuyeres
lime
coal
distributors

Figure 37 - Valve- and injection system of a KMS-converter /26/.

A classification of known combined blowing processes is given in Table VII.

Table VII - Classification of CB-processes /26/.

			From top		From bottom											
												Energy carrier				
Process group	Process	Licensor	O_2	O_2 + lime powder	O_2	O_2 + lime powder	gaseous hydrocarbons	liquid hydrocarbons	N_2; Ar purging	N_2; Ar blowing	CO_2 blowing	coke	coal	liquid hydrocarbons	gaseous hydrocarbons	Post-combustion of converter off-gases
O_2 top blowing	LD-(AC)		●	○												
O_2 bottom blowing	OBM/Q-BOP	Klockner/CRA			○	●	●	○		○						
	LWS	Creusot-Loire				○		●		○						
O_2 top blowing, purging with inert gas	LD-KG	Kawasaki	●							●						
	LD-AB	Nippon Kokan	●													
	LD-BC	CRM	●													
O_2 top blowing, stirring through bottom with inert gas or oxidizing gas	LD-CB	Nippon Kokan	●		●					●	●					
	LD-OTB	Kobe	●		○					●	○					
	LD-STB	Sumitomo	●		○					●	●					
	BSC-BAP	BSC	●													
	LBE	Arbed	●						●							●
Combined top and bottom blowing with O_2	K-OBM	Klockner/CRA	●			●	●	○		○						●
	K-OBM		●		●		●	○		○						○
	K-BOP		●			●	●			○						
	LD-OB	Nippon	●		●		●			○						
	LD-HC			●	●		●			○						
Allothermic blowing	KMS	Klockner/CRA	●			●	●	○		○		●	●	●	●	●
	KS	Klockner/CRA	●			●	●	○		○		●	●	●	●	●
	COIN	Krupp	●		●				○	○		●	●			

○ = possible.
● = applied.

1.4 HOT METAL PRETREATMENT

The purpose of pretreating of hot metal is to decrease its silicon-phosphorous- and/or sulphur-content. When pretreating the hot metal, the work to be done in the converter becomes much less and in the near future, according to the new Japanese model it is only the decarburization which is done in the converter, everything else is done before the converter, see Figure 38.

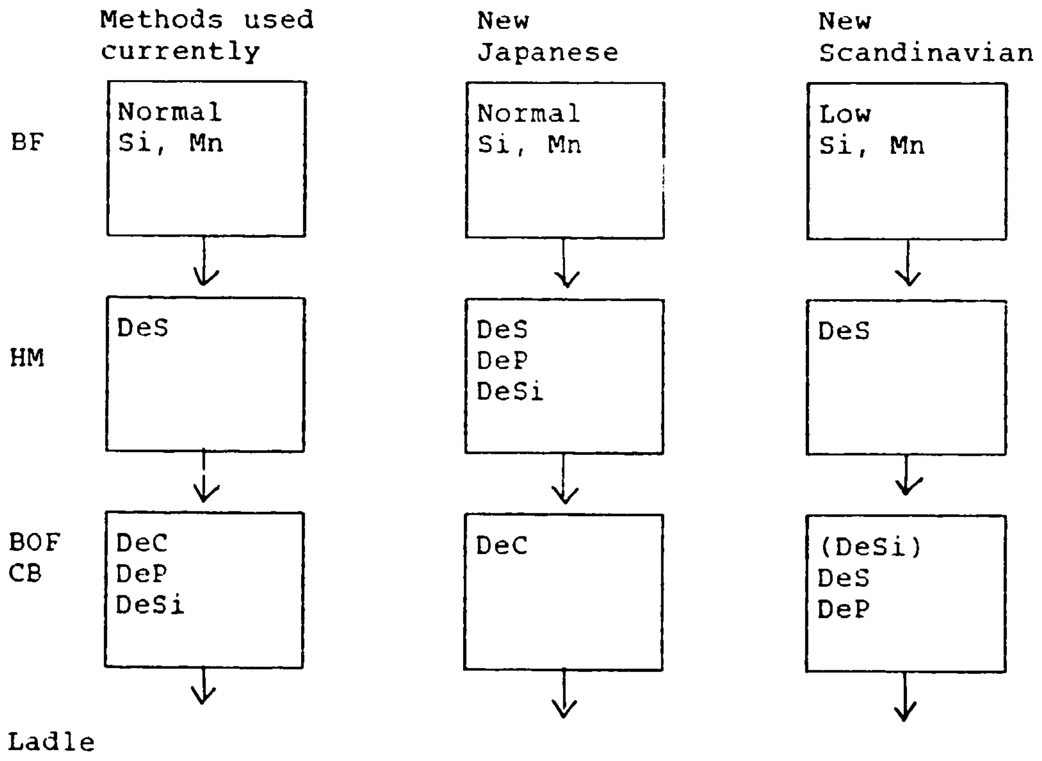

Methods used currently
New Japanese
New Scandinavian
BF
Normal Si, Mn
Normal Si, Mn
Low Si, Mn
HM
DeS
DeS DeP DeSi
DeS
BOF CB
DeC DeP DeSi
DeC
(DeSi) DeS DeP
Ladle

Figure 38 - Steelmaking according to the new Japanese method, new Scandinavian model (low Si HM) and method used currently.

Pretreatment of hot metal is normally carried out in two stages. In the first stage desiliconization is done during tapping from the blast furnace or in a topedo-car. Material used for lowering the silicon content is normally a mixture of iron-ore and mill-scale + oxygen. The amount for mixture added is about 20-30 kg/ton HM. With this method the desiliconization is done to about 0.10-0.15% Si. At the same time some manganese and carbon is being oxidized together with some iron.

In the second step of pretreatment, dephosphorization and/or desulphurization are carried out. Both of them are usually done in a torpedo-car or in a ladle. The reagent for desulphurization is usually CaC_2, CaO or soda-ash and for desphorization it is usually CaC_2, CaF_2 and iron-ore or soda-ash. With simultaneous desphosporization and desulphurization the amount of reagent added is between 20-50 kg/ton HM. Figure 39 shows some reagents used in dephosphorization and desulphurization.

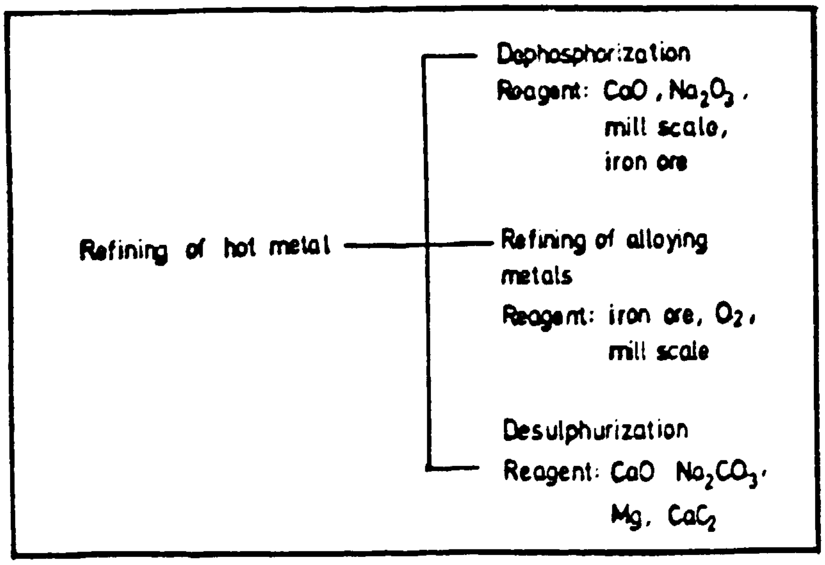

Refining of hot metal
Dephosphorization
Reagent: CaO, Na_2O_3, mill scale, iron ore
Refining of alloying metals
Reagent: iron ore, O_2, mill scale
Desulphurization
Reagent: CaO Na_2CO_3, Mg, CaC_2

Figure 39 - Reagents used in pretreatment of hot metal /27/.

In the following, some descriptions of hot metal pretreatment processes used today are given.

NSC has developed the ORP-process (Optimizing Refining Process) for production of quality steels. ORP consists of three different steps. In the first step desiliconizing is done with a mixture of iron-ore and oxygen. The silicon-content after treatment is about 0.15%. During the desiliconizing step some manganese and carbon losses occur. In the second step, dephosphorization is done with a mixture of iron-ore, CaO and CaF_2 + oxygen. Simultaneously with the dephosphorization a good desulphurization is reached. In the third step decarburization is done in a LD-OB-converter. In the converter some dephosphorization is also achieved and after the converter, the raw steel goes to secondary refining and CC. Process outline of the ORP is shown in Figure 40.

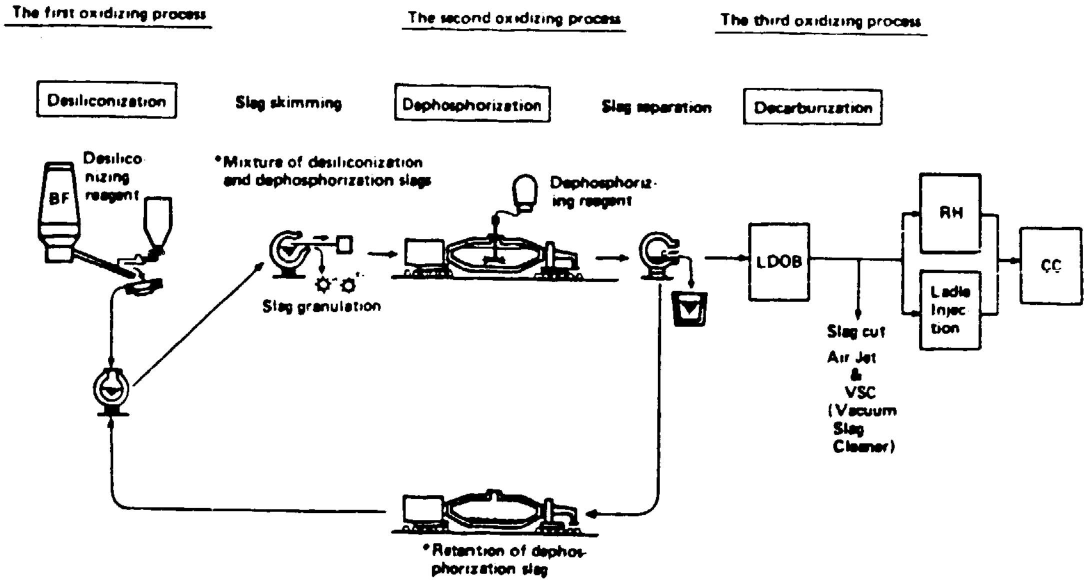

The first oxidizing process
The second oxidizing process
The third oxidizing process
Desiliconization
Slag skimming
Dephosphorization
Slag separation
Decarburization
BF
Desiliconizing reagent
*Mixture of desiliconization and dephosphorization slags
Dephosphorizing reagent
Slag granulation
LDOB
RH
Ladle Injection
CC
Slag cut
Air Jet & VSC (Vacuum Slag Cleaner)
*Retention of dephosphorization slag

Figure 40 - ORP-process /28/.

Used amount of reagents and mixture together with the metal analysis after each step is shown in Figure 41.

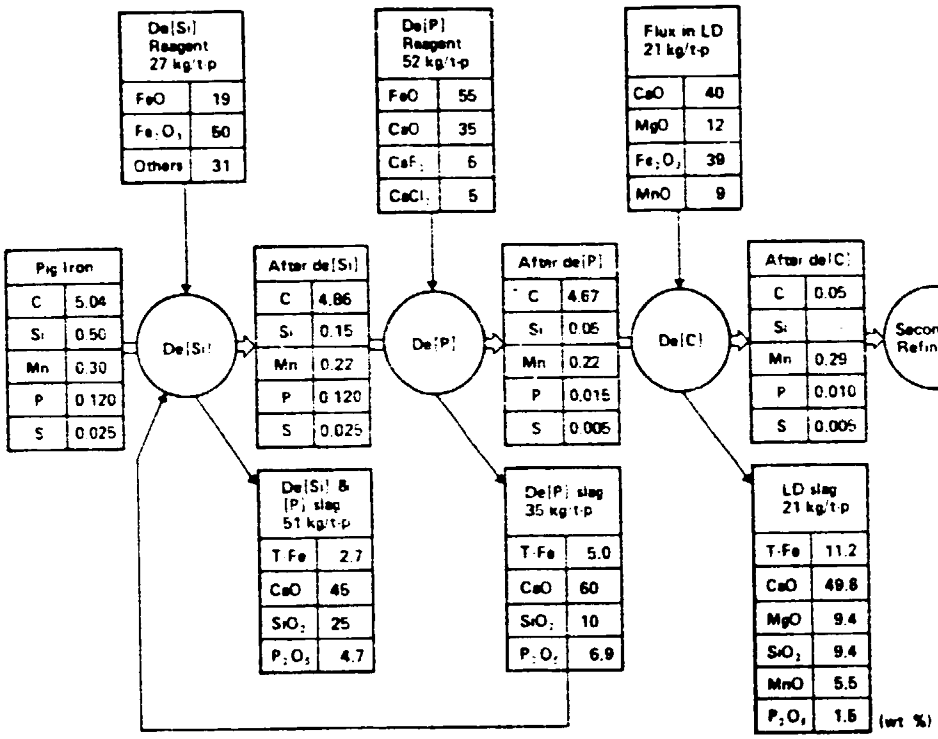

De[Si] Reagent 27 kg/t·p
FeO 19
Fe2O3 50
Others 31
De[P] Reagent 52 kg/t·p
FeO 55
CaO 35
CaF2 6
CaCl2 5
Flux in LD 21 kg/t·p
CaO 40
MgO 12
Fe2O3 39
MnO 9
Pig Iron
C 5.04
Si 0.50
Mn 0.30
P 0.120
S 0.025
De[Si]
After de[Si]
C 4.86
Si 0.15
Mn 0.22
P 0.120
S 0.025
De[P]
After de[P]
C 4.67
Si 0.05
Mn 0.22
P 0.015
S 0.005
De[C]
After de[C]
C 0.05
Si
Mn 0.29
P 0.010
S 0.005
Secondary Refining
Continuous Casting
De[Si] & [P] slag 51 kg/t·p
T·Fe 2.7
CaO 45
SiO2 25
P2O5 4.7
De[P] slag 35 kg/t·p
T·Fe 5.0
CaO 60
SiO2 10
P2O5 6.9
LD slag 21 kg/t·p
T·Fe 11.2
CaO 49.8
MgO 9.4
SiO2 9.4
MnO 5.5
P2O5 1.5
(wt %)

Figure 41 - Material balance in ORP /28/.

Sumitomo has developed the ARP-process (Alkali Refining Process). In ARP, desiliconizing is done in a torpedo-car by injection of iron-ore and oxygen. The silicon-content after treatment is 0.10%. After that the slag is sucked off, the dephosphorization is done with soda-ash injection down to <0.010%P. This slag is also sucked off and the dephosphorization slag goes to a soda-ash recovery-plant. In the third step, decarburization is done in a STB-converter. The ARP-process is shown in Figure 42.

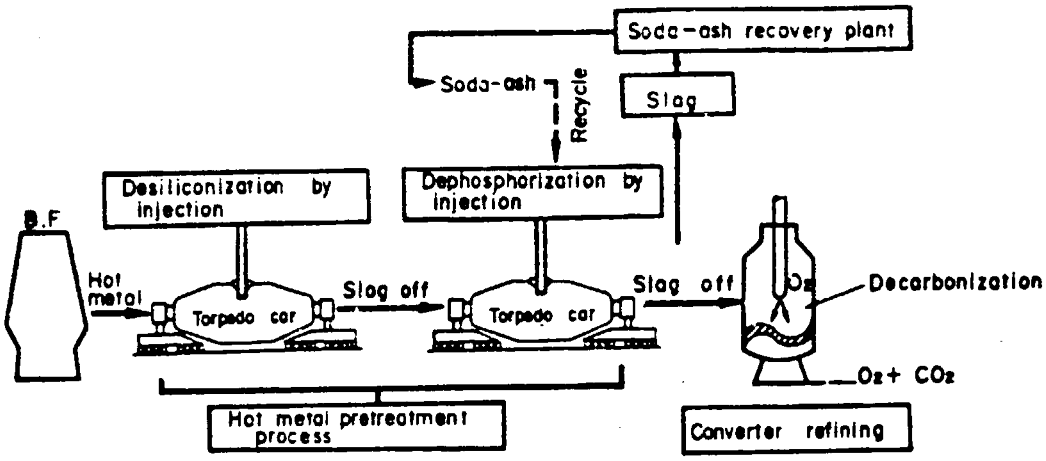

Soda-ash recovery plant
Soda-ash
Recycle
Slag
Desiliconization by injection
Dephosphorization by injection
B.F
Hot metal
Torpedo car
Slag off
Torpedo car
Slag off
O2
Decarbonization
O2+ CO2
Hot metal pretreatment process
Converter refining

Figure 42 - ARP-process /29/.

IRSID has also made trials with a three step oxidation method. In the first step, desiliconization is done with iron-ore and oxygen, in the second step dephosphorization and desulphurization are done with a mixture of iron-ore, CaO and CaF_2. The third step is decarburization. All three steps are done in a LD-HC-converter and a quality-steel is produced. The process is shown in Figure 43.

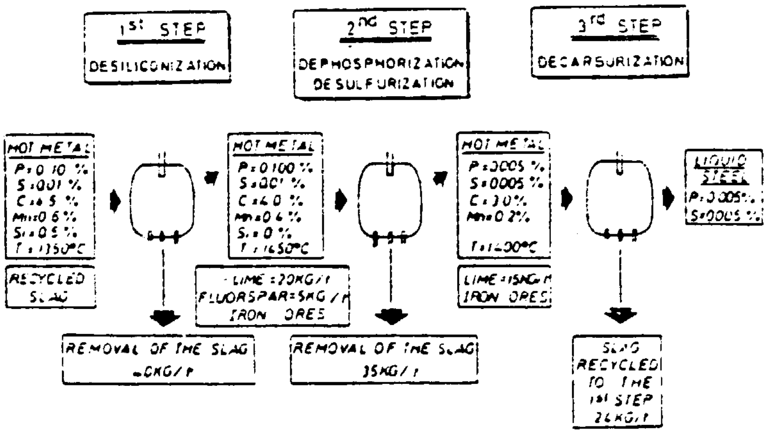

1st STEP
DESILICONIZATION
2nd STEP
DEPHOSPHORIZATION
DESULFURIZATION
3rd STEP
DECARBURIZATION
HOT METAL
P=0.10 %
S=0.01 %
C=4.5 %
Mn=0.6 %
Si=0.5 %
T=1350°C
RECYCLED SLAG
HOT METAL
P=0.100 %
S=0.01 %
C=4.0 %
Mn=0.4 %
Si=0 %
T=1450°C
LIME=20KG/t
FLUORSPAR=5KG/t
IRON ORES
HOT METAL
P=0.005 %
S=0.005 %
C=3.0 %
Mn=0.2 %
T=1400°C
LIME=15KG/t
IRON ORES
LIQUID STEEL
P=0.005 %
S=0.005 %
REMOVAL OF THE SLAG
60KG/t
REMOVAL OF THE SLAG
35KG/t
SLAG RECYCLED TO THE 1st STEP
26KG/t

Figure 43 - Production of low-impurity steels /1/.

Kobe Steel has a four-step pilot-plant process. The first step is desiliconization done with mill-scale. After this dephosphorization and desulphurization is done with a mixture of CaO + CaF_2 + iron-ore. The third step is a second desulphurization with CaC_2. In the fourth step, decarburization is done in a LD-OTB-converter. The process and material flows are shown in Figure 44 a and 44 b.

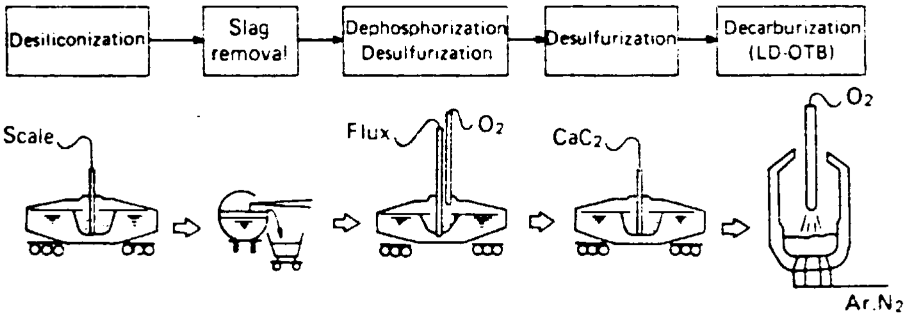

Desiliconization
Slag removal
Dephosphorization Desulfurization
Desulfurization
Decarburization (LD-OTB)
Scale
Flux
O_2
CaC_2
O_2
Ar.N_2

Figure 44 a - Kobe Steel-process /29/.

Experimental conditions of Hot metal Pretreatment

Desiliconization	Scale consumption	15 ~ 25 Kg/T
	Carrier gas (N_2)	400 Nm^3/Hr
	Injection rate	300 ~ 350 Kg/Min.
Dephosphorization Desulfurization	Flux consumption	25 ~ 35 Kg/T
	Injection rate	300 ~ 400 Kg/Min
	Oxygen consumption	3.5 ~ 4.5 Nm^3/T

Hot metal chemical composition and temperature

		Ordinary process	Experimental process
Hot metal	[C]	4.55 %	4.00 %
,,	[Si]	0.30 %	0.02 %
,,	[Mn]	0.45 %	0.29 %
,,	[P]	0.090 %	0.015 %
,,	[S]	< 0.015 %	< 0.015 %
,,	[Ti]	0.05 %	tr.
,,	Temp.	1370°C	1326°C

Figure 44 b - Material flow and HM-composition in Kobe Steel-process /29/.

Kawasaki Steel has developed the LLB-process (Lime Less Blowing). This process exists in two different variants. In the first, desiliconization is done in a torpedo-car with iron-ore and oxygen and then desphosporiation is done in a K-BOP-converter. The second variant is desiliconization and desphosporization in a torpedo-car and after that decarburization in a K-BOP-converter. The LLB-process is shown in Figure 45.

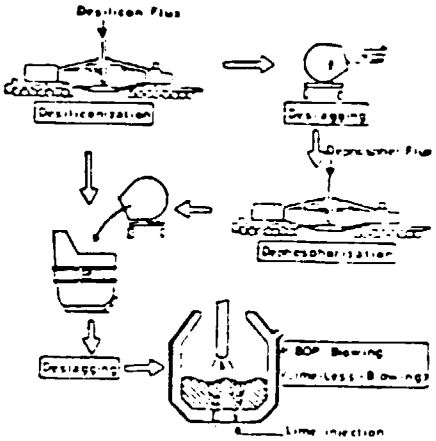
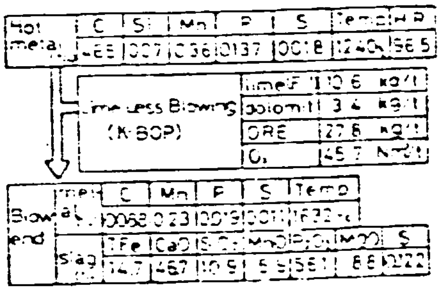

Desilicon Flux
Desiliconization
Deslagging
Dephosphorizer Flux
Dephosphorization
Deslagging
BOP Blowing
(Lime-Less-Blowing)
Lime injection

Figure 45 - LLB-process /30/.

Table VIII shows material flows in the LLB-process (desiliconized hot metal). As injection material CaO, dolomite and iron-ore + oxygen are used.

Table VIII - Material flows in LLB /30/.



Hot metal (%)	C	Si	Mn	P	S	Temp	H P
	4.55	0.07	0.36	0.137	0.018	1240°C	56.5

Lime-less Blowing (K-BOP)

Lime(F)	10.6	kg/t
Dolomite	3.4	kg/t
ORE	27.6	kg/t
O_2	45.7	Nm^3/t

Blow end								
metal (%)	C	Mn	P	S	Temp			
	0.068	0.23	0.019	0.011	1632°C			
slag (%)	T.Fe	CaO	SiO_2	MnO	P_2O_5	MgO	S	
	14.7	46.7	10.9	5.9	5.61	8.8	0.222	

1.5 ECONOMICAL ASPECTS IN COMBINED BLOWING

1.5.1 Hot metal pretreatment

Pretreatment of hot metal is quite costly, but a part of the pretreatment-costs are coming back already in the converter. Cost calculations of pretreatment are quite difficult, but in the following pages an approximate cost-balance for pretreating hot metal is given.

Desiliconization

Material used for desiliconization is usually iron-ore or mill scale. These reagents are quite cheap. Other costs are the costs for injection, lances, oxygen, iron-losses to slag and loss of carbon and manganese. Oxygen and material yields are quite high in desiliconization.

Costs

- Iron-ore or mill scale: 30 kg/ton HM x 0.3 SEK/kg = 9 SEK/ton
- Oxygen: about 8 m^3n/ton x 0.4 SEK/m^3n = 3.2 SEK/ton
- Lance-costs (300 ton) = 2 SEK/ton
- Costs for manpower = 0.5 SEK/ton

= 14,7 SEK/ton

To these costs must be added costs for deslagging, iron losses and costs of refractories.

The costs for desiliconization from 1% to 0.15% Si in hot metal are approximately 15 SEK/ton + capital costs + iron losses + refractories + deslagging etc.

Desulphurization

Desulphurization is usually done with soda-ash or CaD-mixture (CaC_2 + gas former). The amount of material used is 5-7 kg/ton.

Costs

- Mixture CaD: 5 kg/ton x 2.5 SEK/kg = 12.5 SEK/ton
- Lance-costs (300 ton) = 2 SEK/ton
- Manpower = 0.5 SEK/ton
- Iron losses to slag = 4.0 SEK/ton
- Refractories = SEK/ton

19 SEK/ton

The total costs for desulphurization are about 19 SEK/ton + capital costs for the equipment needed.

Dephosphorization

Dephosphorization is done with either soda-ash or lime based mixtures. In both these cases, desulphurization is done at the same time.

Costs

	Soda ash	Lime based reagent
- Reagent	30 SEK/ton (20 kg/ton)	15 SEK/ton (30 kg/ton)
- Oxygen: 3 m^3n/ton x 0.4 SEK/ton	12 SEK/ton	1.2 SEK/ton
- Manpower	0.5 SEK/ton	0.5 SEK/ton
- Lance-costs	2.0 SEK/ton	2.0 SEK/ton
- Refractories	5.0 SEK/ton	-
- Iron losses	2.0 SEK/ton	2.0 SEK/ton
	40.70 SEK/ton	20.70 SEK/ton

The use of soda-ash requires a recovery plant for soda-ash from the dephosphorization slag in order to reach acceptable treatment costs.

1.5.2 Economical advantages with combined-blowing

The largest economical savings with combined-blowing are gained from better iron-yield and lower [O]-content in the steel, which saves both manganese in the steel and alloying elements. Better mixing results in higher lime-yield and better desulphurization and dephosphorization in the converter. Better lime-yield also saves lime, because the aimed basicity is achieved with a lower amount of lime. Higher costs with combined blowing come from lower scrap melting capacity (depending on the scrap-price) and increased gas consumption due to the use of bottom-gas (nitrogen, argon, oxygen, propane, CO_2 etc).

Table IX shows data for all possible material- and cost savings from different steelworks, which have reported their results with combined blowing.

ble IX - Material- and cost-savings with combined blowing.

rocess	LBE	LBE	LBE	NK-CB	K-BOP	LD-KG	Krupp	Krupp	Hoesch	K-OBM	KMS
eference	12	7	7	31	32	32	17	17	33	26	26
ron yield	+1%	+0.6%	+0.5%	+0.8%	+1.0%	+0.15					
ime kg/ton	+2	-3	+4.5	-3.0	-5.0	-2.0	-0.5	-0.5	-5.0	-19	-31
olomite kg/ton	-13	-8	-18.0							-12	-14
luorspar kg/ton	-4									-2	-2
luminium kg/ton		-0.4	-0.3	-0.35	-0.2	-0.05	-0.18	-0.12	-0.8	-0.3	-0.3
eMnC kg/ton		-0.45	+0.3	-1.2			-0.32	-0.18		-1.9	-1.9
eMnA kg/ton		-0.2	-0.7								
n in steel kg/ton	+0.04				+0.07	+0.03					
lowing time				-1.0 min							
as recovery Mcal/ton)					+36.0						
otal profit		8.7 FF/ton ≈ 1 $/ton	8.9 FF/ton ≈ 1 $/ton						1.46 DM/ton ≈ 0.5 $/ton		

Gunningham has compared production costs for three different steel qualities made in normal LD, LD with bottom stirring and combined blowing. These comparisions are made with and without post-combustion of CO. Table X shows the basis for calculations and Table XI the calculations.

Table X - Basis for cost calculations /3/.

	Condition		
	A	B	C
Aim turndown:			
C, %	0.05	0.15	0.25
S(max), %	0.025	0.025	0.025
P(max), %	0.010	0.010	0.010
Temperature, °F	2950	2935	2920
Aim ladle composition:			
C, %	0.09 max.	0.16/0.20	0.26/0.30
Mn, %	0.50	0.75	1.00
Al, %	0.05	0.05	0.05

Product mix is:

Carbon range	Product mix
<0.10%	50%
>0.15% <0.20%	30%
>0.25% <0.30%	20%

Unit costs — The assumed costs used in the comparisons are:

Hot metal, $/ton		170.00
Scrap (average), $/ton		100.00
Burnt lime, $/ton		
lump		55.00
pulverized		70.00
Dolomitic burnt lime, $/ton		55.00
Fluorspar, $/ton		96.00
Gases, $/100 cu ft		
oxygen		0.15
nitrogen		
—combined blowing		0.15
—bottom stirring		0.30
argon		2.50
natural gas		0.45
air		0.05
Vessel refractories (brick, gunning and slagging practice), $/ton liquid steel:		
BOF (1500 heats)		
brick	0.70	
gunning/slagging	0.30	
Total	1.00	
Bottom stirring (1500 heats—barrel, 750 heats—bottom)		
brick	0.82	
gunning/slagging	0.38	
Total	1.20	
Combined blowing (1500 heats—barrel, 500 heats—bottom)		
brick	1.11	
gunning/slagging	0.29	
Total	1.40	
Maintenance, $/ton liquid steel		
BOF		3.00
Bottom stirring		3.05
Combined blowing		3.20
Production labor*, $/ton liquid steel		
BOF		3.93—4.10
Bottom stirring		3.80—4.13
Combined blowing		3.69—4.02
Ferromanganese (78%), $/ton		650.00
Aluminum, $/ton		1,200.00
Overall plant overhead and fixed costs, $/ton finished product		130.00
Finished product average selling price, $/ton		430.00

---

* Production labor is prorated based on the number of tons produced each day by each process. $4.00/ton is the base for 6400 tons of liquid steel/day by the BOF overall process.

Table XI - Production costs for LD, LD with bottom stirring and combined blowing /3/.

	Units	BOF	Bottom-stirring with post-combustion	Combined blowing with post-combustion
Aim turndown—0.05% C, 0.025% S, 2950°F				
Hot metal[1]	lbs	1643.18 (71.91%)	1588.18 (70.32%)	1543.92 (69.59%)
Steel scrap[2]	lbs	641.93 (28.09%)	670.38 (29.68%)	674.75 (30.41%)
Burnt lime	lbs	147.33	145.80	124.05
Burnt dolomite	lbs	44.08	35.67	12.28
Fluorspar	lbs	5.00	2.00	—
Oxygen	scf	1868.60	1859.80	1753.51
Air	scf	—	6.01	182.66
Natural gas	scf	—	—	46.76
Nitrogen	scf	—	61.60	182.67
Argon	scf	—	15.32	15.22
HC FeMn, aim 0.50%	lbs	14.41	13.63	11.13
Al, aim 0.05%	lbs	3.70	3.45	3.22
Yield[3]	%	87.52	88.55	90.14
Aim turndown—0.15% C, 0.025% S, 2935°F				
Hot metal[1]	lbs	1692.34 (74.19%)	1632.48 (72.33%)	1586.76 (71.47%)
Steel scrap[2]	lbs	588.78 (25.81%)	624.47 (27.67%)	633.46 (28.53%)
Burnt lime	lbs	185.48	178.93	145.76
Burnt dolomite	lbs	16.68	11.55	0.68
Fluorspar	lbs	12.50	9.50	7.50
Oxygen	scf	1810.44	1808.66	1711.74
Air	scf	—	8.99	192.90
Natural gas	scf	—	—	45.65
Nitrogen	scf	—	59.81	182.67
Argon	scf	—	15.32	15.22
HC FeMn, aim 0.75%	lbs	21.19	20.19	16.70
Al, aim 0.05%	lbs	2.86	2.78	2.70
Yield[3]	%	87.68	88.62	90.06
Aim turndown—0.25% C, 0.025% S, 2920°F				
Hot metal[1]	lbs	1712.88 (75.07%)	1651.59 (73.12%)	1605.73 (72.25%)
Steel scrap[2]	lbs	568.69 (24.93%)	607.17 (26.88%)	616.84 (27.75%)
Burnt lime	lbs	202.86	193.58	148.45
Burnt dolomite	lbs	3.23	—	—
Fluorspar	lbs	17.50	14.50	12.50
Oxygen	scf	1771.60	1771.94	1676.01
Air	scf	—	10.74	207.02
Natural gas	scf	—	—	44.90
Nitrogen	scf	—	58.52	182.67
Argon	scf	—	15.32	15.22
HC FeMn, aim 1.00%	lbs	26.37	25.44	21.76
Al, aim 0.05%	lbs	2.38	2.32	2.27
Yield[3]	%	87.66	88.54	89.99

[1] Hot metal: 4.28% C, 0.80% Mn, 0.050% S, 0.070% P, 1.00% Si.

[2] Scrap: 50 lbs pit scrap, 100 lbs home scrap, balance No. 1 heavy melting (/ton of liquid steel).

[3] Yield: liquid steel/(hot metal + scrap).

Heat costs, $/ton liquid steel, for BOF, bottom stirring with post combustion and combined blowing with post combustion

	Turndown carbon			
	0.05%	0.15%	0.25%	Overall
BOF	194.91	198.81	201.29	197.36
Bottom stirring	191.51	195.34	197.85	193.93
Combined blowing	187.08	191.00	193.47	189.53

Heat costs, $/ton liquid steel, for BOF, bottom stirring without post combustion and combined blowing without post combustion

	Turndown carbon			
	0.05%	0.15%	0.25%	Overall
BOF	194.91	198.81	201.29	197.36
Bottom stirring	194.70	198.55	201.01	197.12
Combined blowing	190.01	193.91	196.34	192.45

As shown in Table XI, the production costs per ton of steel are approximately 8 US $ lower with combined blowing than with conventional LD with post-combustion of CO.

Von Bogdany et al. have also made calculations where they have compared normal LD with K-OBM (K-BOP) and KMS-process. Their calculations are made for low carbon steel. In Table XII the cost situation is shown and in Table XIII the consumption of material and cost savings are shown.

Table XII - Cost situation in Von Bogdany's calculations /26/.

Hot metal, steel and lime compositions used in the economic estimate are:

Hot metal (at 1340°C)	C 4.2%, Si 1.0%
Turndown (at 1620°C)	C 0.05%
Steel	Mn 0.50%, Si 0.2%, Al 0.05%
Lime powder	CaO 90%
Lump lime	CaO 90%
Dolomitic lime	CaO 56%, MgO 38%

The material costs used are:

Hot metal, DM/tonne	400
Steel scrap (average), DM/tonne	200
Alloys, DM/tonne	
FeMn	800.00
Al	2500.00
Fe Si	1400.00
Slag making additions, DM/tonne	
Burnt lime	110
Lime powder	120
Dolomitic lime	110
Fluorspar	200
Gases, DM/1000 N cu metre	
O_2	220
N_2	40
Air	30
CH_4	470
Ar	2000
Electrical power, DM/1000 kwhr	100
Maintenance, DM/tonne	
LD	5.00
Bottom stirring	5.10
K-OBM	5.50
KMS	6.00
Labor, DM/tonne	
LD	7.00
Bottom stirring	6.70
K-OBM	6.40
KMS	8.30
Refractories (including bricks, gunning material and slagging material), DM/brick tonne	1800.00
Lignite coke, DM/tonne	260.00

(In the U.S., a coal cost of DM 170/tonne is expected.)

The economic comparison is based on the following scrap rates:

LD	310 kg/tonne liquid steel
Bottom stirring	309 kg/tonne liquid steel
K-OBM	334 kg/tonne liquid steel
KMS	540 kg/tonne liquid steel

For bottom stirring, the assumption is made that the degree of post-combustion of the off-gases in the converter is similar to the LD.

Other conditions — Steel production with the different processes are estimated at:

LD	3.80 million tonnes/year
Oxygen top blowing with bottom stirring	3.95 million tonnes/year
K-OBM	4.20 million tonnes/year
KMS (50% scrap rate)	3.20 million tonnes/year

The amount of investment for the conversion of two 200-tonne LD converters to the following processes is estimated to be:

Bottom blowing	DM 6 million
K-OBM with lime injection	DM 30 million
KMS with coal injection	DM 50 million

(Rate of exchange: DM 2.60 = US $1.00)

Table XIII - Comparison LD, LD with bottom stirring, K-OBM and KMS /26/.

		Consumption				Cost, DM/liquid steel tonne			
Type	Unit	LD	Bottom stirring	K-OBM	KMS	LD	Bottom stirring	K-OBM	KMS
Hot metal (Fe 93.5 %)	kg/tonne	796	791	744	540	318.40	316.40	297.60	216.00
Steel scrap (Fe 96 %)	kg/tonne	310	309	334	540	62.00	61.80	66.80	108.00
Total	kg/tonne	1106	1100	1078	1080	380.40	378.20	364.40	324.00
Alloys:									
FeMn	kg/tonne	5.9	5.2	4.0	4.0	—	—	—	—
FeSi	kg/tonne	3.3	3.3	3.3	3.3	—	—	—	—
Al	kg/tonne	1.8	1.6	1.5	1.5	—	—	—	—
Total	kg/tonne	11.0	10.1	8.8	8.8	13.84	12.78	11.57	11.57
Total metallic input	kg/tonne	1117.0	1110.1	1086.8	1088.8	394.24	390.98	375.97	335.57
Slag making additions:									
Lump lime	kg/tonne	69	66	—	—	7.59	7.26	—	—
Powdered lime	kg/tonne	—	—	50	38	—	—	6.00	4.56
Dolomitic lime	kg/tonne	20	16	8	6	2.20	1.76	0.88	0.66
Fluorspar	kg/tonne	2	1	—	—	0.40	0.20	—	—
Coal or lignite	kg/tonne	—	—	—	51	—	—	—	13.31
Total		91	83	58	95	10.19	9.22	6.88	18.53
Gases:									
O_2	N cu metre/tonne	48	48	45	84	10.56	10.56	9.90	18.48
Air	N cu metre/tonne	—	0.2	5	7	—	0.01	0.15	0.21
CH_4	N cu metre/tonne	—	—	1.2	2.2	—	—	0.56	1.03
N_2	N cu metre/tonne	—	2	5	12	—	0.08	0.20	0.48
Ar	N cu metre/tonne	—	0.4	—	—	—	0.80	—	—
Electrical power	kwhr/tonne	25	25	25	35	2.50	2.50	2.50	3.50
Credit for off-gas	GJ/tonne	0.64	0.63	0.55	1.30	−8.16	−8.03	−7.01	−16.58
Refractory	—	—	—	—	—	2.49	2.49	3.09	3.86
Maintenance	—	—	—	—	—	5.00	5.10	5.50	6.00
Labor (production)	—	—	—	—	—	7.00	6.80	6.40	8.30
Investment, million DM	—	—	—	—	—	—	6	30	50
Capital service,	—	—	—	—	—	—	0.08	0.36	0.78
Loan repayment,	—	—	—	—	—	—	0.30	0.71	1.56
Liquid steel cost	—	—	—	--	—	423.82	420.89	405.19	381.72
Production, million tonnes/year	—	3.80	3.95	4.20	3.20	3.80	3.95	4.20	3.20
Yield, %	—	90.4	90.9	92.8	92.5	90.4	90.9	92.8	92.5

Conditions: Hot metal: C 4.2 %, Si 1.0 %, Mn 0.8 %, temperature 1340°C.
Turndown: C 0.05 %, temperature 1630°C.
Finished steel: Mn 0.5 %, Si 0.2 %, Al 0.05 %.
Capital service: amortized over 10 years plus 10 % interest on half of investment.

As shown in Table XIII, the production costs are approximately 18 DM (6 US $) lower per ton steel in K-OBM compared with conventional LD.

1.6 CONCLUSIONS

Combined blowing has been compared with conventional LD-process. The advantages and disadvantages of combined blowing have been presented. All known combined blowing processes have been presented. Hot metal pretreatment has been discussed and hot metal pretreatment-processes combined with combined blowing have been presented. Further economical aspects both in pretreating hot metal and in steelmaking with combined blowing have been discussed.

Combined blowing is a new era of steelmaking. It gives more flexibility, lower production costs and better steel quality. All presented combined blowing processes are suitable for Indian conditions. Pretreatment of hot metal should be done to decrease the slag-amount in the converter. Also the separation of blast furnace slag should be done carefully in order to avoid charging of BF-slag into the converter. Due to the very specific Indian conditions an installation of combined blowing system should be done and in that way collect data for further development.

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Appendix 2

MEFOS
METALLURGISKA
FORSKNINGSSTATIONEN

Forskningsuppdrag	Konto	Datum	Reg nr
UNIDO/INDIA	4444	1985-02-20	MF85015

SUBJECT: DP/IND/036 - CONTRACT NO 84/66 - EXPERT STUDIES

2. DESIGN DEMONSTRATION UNIT

by

Nils-Olov Lindfors

Postadress
MEFOS
Box 812
951 [illegible]

Telefon
0920-556 40

Telex
80482 MEFOS S

Bankgiro
[illegible]

Postgiro
6 18 00-9

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Instrumentation air system
Valve lists
Instrumentation and control system specification
Rotary joint connection
Installation sketchs
Slag indication systems

2.1 BACKGROUND

Already in the late sixties, tests started at MEFOS with permeable elements in the bottom of a 6-tons LD-converter to improve agitation in the bath. Since than a great development of bottom gas injection has occured all over the world. To a very great extent LD-converters have been transformed into combined blown converters. As an example, in Scandinavia today 8 converters out of 10 have been transformed to combined blowing, five of these operating with tuyeres and three with permeable blocks.

On the bases of a SAIL-proposal for one of the 100/130 t converters at Bokaro, MEFOS has designed the complete systems for CTBB.

2.2 GENERAL METALLURGICAL ASPECTS WHEN INTRODUCING CTBB

A number of advantages are generally achieved, when changing from normal LD-operation to CTBB (Concurrent Top and Bottom Blowing). It is important to state that this means a simplification of the operation not a complication. In the following chapters the main differences will be explained, comparing LD with CTBB.

2.2.1 Iron oxide content of the final slag

The Fe_{tot}-content in the slag at turn down will be reduced with CTBB. The stirring is much improved and mixing time is reduced to about 40 seconds compared to LD about 90 seconds. The table below shows the normal decrease of Fe_{tot} as a function of turn down carbon.

% C	0.08	0.06	0.04
LD-Fe_{tot}	13.2	16.7	22.5
CTBB-Fe_{tot}	8.8	11.5	14.2

The improved stirring also normally gives a reduced Fe_{tot} in the slag during the blow.

2.2.2 Oxygen content of the steel - yield for alloying element

The oxygen content of the steel will be drastically decreased with CTBB. Due to dilution of the produced CO-gas the decrease of oxygen compared to LD will be as follows:

% C	0.08	0.06	0.04
Δ ppm oxygen	20	100	250

Normally the product $\%\underline{C} \times \%\underline{O}$ is as follows:

LD $\%\underline{C} \times \%\underline{O} = 0.0040$
CTBB $\%\underline{C} \times \%\underline{O} = 0.0020$

This decrease in oxygen content will result in lower consumption of alloying elements in a normal range of:

AL:	0.02-0.3 kg/ton of steel
FeSi:	0.2-0.3 kg/ton of steel
FeMn:	0.2-1.0 kg/ton of steel

2.2.3 Slag formation, P- and S-refining

CTBB gives better stirring and a faster dissolution of lime with improved contact between slag and metal. This results primarily in a better lime yield. Therefore normally the limeconsumption is decreased, in the range of 5 kg/ton. Normally the phosphourus content is slightly reduced and sulphur reduced with 0.002-0,005%.

2.2.4 Process control

When refining CTBB the process is closer to equillibrium. This gives less overoxidization of the slag and the risks for slopping and scullformation decreases, resulting in better control and higher metallic yield.

2.2.5 Scrapmelting capacity

CTBB gives less oxidization of Fe to the slag and together with a cooling effect from the purging gas a marginal decrease of the scrapmelting effect will occur. The improved stirring gives a faster scrapmelting pattern which results in the possibility to melt bigger pieces of scrap.

2.2.6 Lining wear

The lining wear rate will decrease in the wall of the vessel since the iron oxide content of the slag can be decreased. The wear rate of the bottom will however increase due to increased stirring and turbulence around the bottom elements. The location of the bottom elements is also done in such a way that consideration is given to the penetration area of the oxygen lance and the wear rate of the wall. Normally a higher quality of refractories are installed in the bottom so that the overall campaign lengths will be longer when introducing CTBB.

2.3 MEDIA SYSTEM

The CTBB system involves a system for injection of nitrogen (N_2) alternative argon (Ar) through 6-8 bottom elements in one 100/130 t converter at Bokaro. The system is designed in such a way that both permeable blocks and high pressure MEFOS-tuyeres can be used. Initially the plant will use permeable blocks while the enclosed design is laid out for this alternative. Component list is enclosed.

2.3.1 Technical description

The design flow sheet and logistics schedule is shown in the enclosed drawing (Calor Celsius 3011-4014-1:1). Incoming nitrogen resp. argon at a delivery pressure of 18 bar is controlled with shut off valves (double valves with depressurizing out of the valve station room with a third valve). The N_2- resp. Ar-system can also be manually closed or opened with hand operated shut off valves.

The pressure reduction for respecitive gases are done with remote controlled pressure reduction valves with the pressure range 2-8 bar. The separate lines are then connected to a central line where the total flow rate measurement is installed. Thereafter follow eight individual lines. In these lines the flow rates are controlled and measured. The eight lines are then connected to a rotary joint. The rotary joint is shown in the enclosed drawing. Ten connections are made, since two spare connections will be used for elements in the tap hole region. From the rotary joint the connection to the elements are made via a connection block and compensators for each element according to enclosure.

Dimensioning date for the piping system:

Total maximum flow rate:	0.15 m^3n/ton·min
Total maximum flow rate per element line:	200 m^3n/h
Normal flow rate per element line:	0.05 m^3n/ton·min
Reduced pressure range:	2-8 bar
Gas temperature of N_2 and Ar:	min. 0°C max. 45°C

2.3.2 By-pass system

When tuyeres are used as bottom elements it is essential to always maintain the minimum gaspressure during blowing, charging, tapping etc. The by-pass system is also a safety system for example at failure in the electrical supply. The minimum pressure for the Bokaro-converter we recommend to be 3.5 bar backpressure for each element.

The by-pass system is initially only connected to the nitrogen line, however space should be made available also to connect the argon line in the future when argon also will be available. The distribution for each individual line is adjusted before start up of a campaign.

2.4 INSTRUMENTATION AND CONTROL

The system can be controlled with three basic systems,

2.4.1 Conventional analog regulation equipment with relay system

The system is controlled via a relay pulpet located according to enclosure. The operator adjusts pressure and flow rates from controllers in the pulpet. The pulpet must be inclined according to enclosure, since the controllers must be installed with a maximum angel of 30° to the vertical plane. All flow rate measurements of orifice type have separate compensation for temperature and pressure. Compensation for the type of gas media is not done.

2.4.2 Computer based system

A microcomputer is used for logistics for the valve station and control of preprogrammed blowing programs. All compensations of flow rate measurements are done by the computer. Raw signals are treated in the computer and the flow rate is presented compensated for pressure, temperature and type of media. The system can be operated in both auto and manual modes. One disadvantage is that if failure occur in the computer system regulation of the system is not possible. This means that only blowing via the by-pass system is possible.

2.4.3 Combination of conventional and computer based control

This system means that the logistics are based on the conventional system according to alternative 1. The computer is only used to automatically give signals to the regulators for preprogrammed blowing programs and to compensate flow-rate measurements for type of media. This system will fulfill all safety aspects and means that if computer failure occurs the blowing will proceed with the last set points and regulation is done via the relay system. For the Bokaro-situation we recommend this system. If this system is used for the first installation the staff will gain experience with control from computer based system. For future installation it is probable that completly computer based control will be installed.

Component list for this alternative is enclosed.

Since instrumentation air is not available in the Bokaro plant, nitrogen is used according to enclosure.

2.5 IMPLICATION FOR CHANGE OVER TO TUYERE BASED PURGING SYSTEM

In the future we see advantages for Bokaro to use tuyeres as purging elements. These can easily be produced in the plants own workshop. The type of tuyeres should be annular slit tuyeres of MEFOS-type with a plugged inner tube, using an increased back pressure.

When changing over to tuyeres, minor changes have to be done in the system. Parts in the pressure reduction valves and the regulation valves must be changed. Also the by-pass system will have to be adjusted, to assure a back pressure before the tuyeres. Also minor changes can be needed for the connection to the elements in the converter bottom.

2.6 SPARE PARTS

Recommended spare parts for the control equipment are as follows:

1	Pressure transmitter type AEC 200
1	Alarm unit type RMG 19
2	Diff-pressure transmitters type AEI 200
2	Electronic controllers type Protronic PS
2	Indicator type Ha 72/240
2	I/O-converters type TEIP
1	Measuring amplifier type TEU 6
1	Control valve Masoneilan Micro Pac
2	Supply unit type TZN 123 with square roof extraction
1	Computing unit type TZA 305
1	Resistance thermometer Pt 100 ohm
1	Integrator type TZIF 3

For computer system we recommend the following spare parts:

1	SattCon 31
1	ROM 30
1	RAM 30
1	24V5ARC
1	PIOB
1	PBAD
1	PSB
1	ICA 420
1	OCAH 420
1	IDPG 48
1	ORG 24
1	VT 101

2.7 COST ESTIMATIONS

The costs for the system depend very much on the alternative used for control strategy. For the complete system including erection the cost is estimated as follows:

Alt 1

Conventional analog regulation equipment with relay station.
MSEK: 3.8

Alt 2

Computer based system with possibility of manual operation (computer based).
MSEK: 3.8

Alt 3

Alt 2 and alt 2 in combination.
MSEK: 4.1

If two extra element lines are included an extra cost estimated at SEK 50 000.

If the by-pass system for argon is included an extra cost of SEK 40 000 will accrue.

The extra cost for suggested spare parts are estimated at SEK 200 000.

This costestimation is based upon the valve station being built in Sweden and then transported and erected in Bokaro. Transportation cost is also included. The valve station is installed in a steel container and totally prefabricated. Installation of instrumentation and control equipment are, to a major extent done at Bokaro. It is also forseen that the modifications on the existing converter bottom are done by the plant (drilling of holes). Operation assistance and consultation after performance test are not included. Education and training programme are also not included.

2.8 SLAG ARRESTER SYSTEM

2.8.1 Background

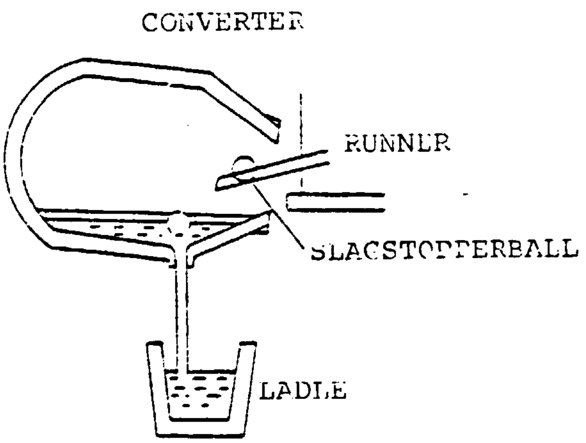
The amount of furnace slag carried over from the converter into the ladle have a harmful effect on the steel quality and on the subsequent ladle treatment e.g. on desulphurization, deoxidation and yields of alloying elements etc. An effective metal and slag separation before, during and after the tapping of the vessel would greatly increase the possibilites of a successful ladle operation.

2.8.2 Methods

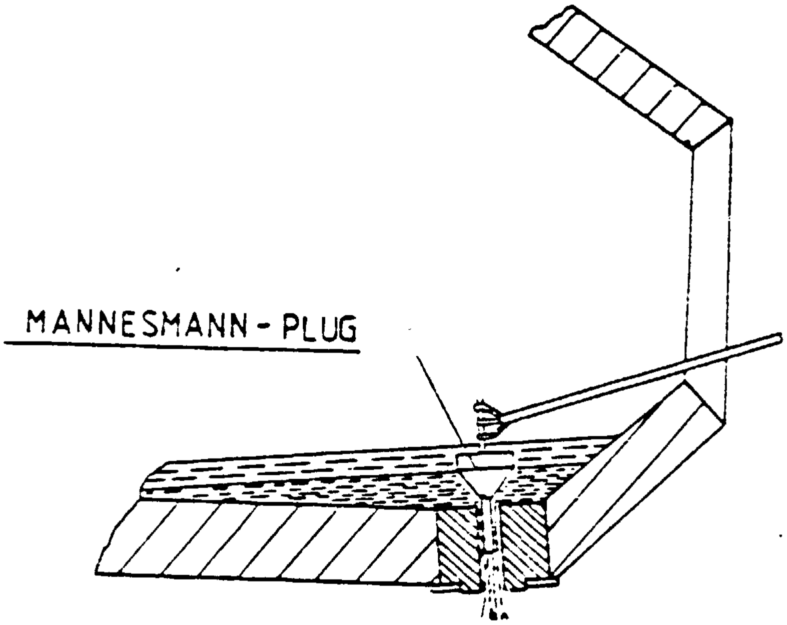
To be able to reduce slag carry over to the ladle different methods have been used. The following systems can be used:

Before	During		After
Slag raking	Inner:	Ball	Slag raking
Stiff slag		Plug	Suction
		Fleet	
		Gaspurging	
	Outer:	Mechnical stopper	
		Pneumatic stopper	
		Sliding gate	
		Intermediate ladle	

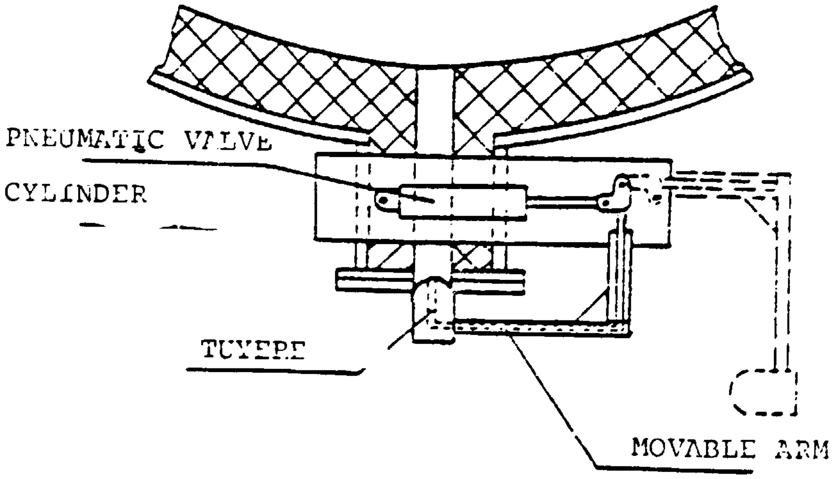
Schematic principles for some different systems are shown below.


CONVERTER
RUNNER
SLAGSTOPPERBALL
LADLE

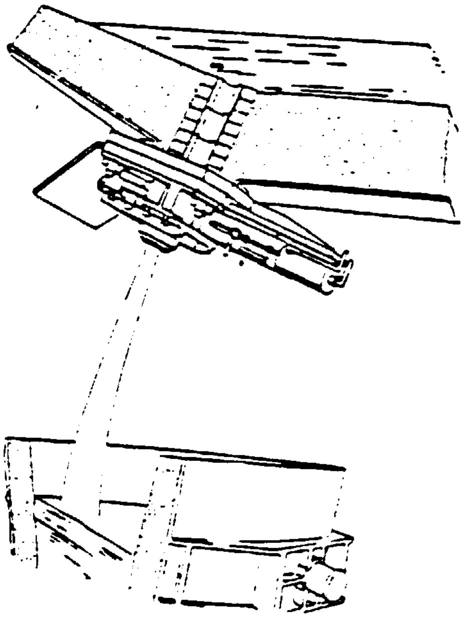
Ball


MANNESMANN - PLUG

Plug


PNEUMATIC VALVE
CYLINDER
TUYERE
MOVABLE ARM

Vöest-Alpine stopper



Sliding gate stopper

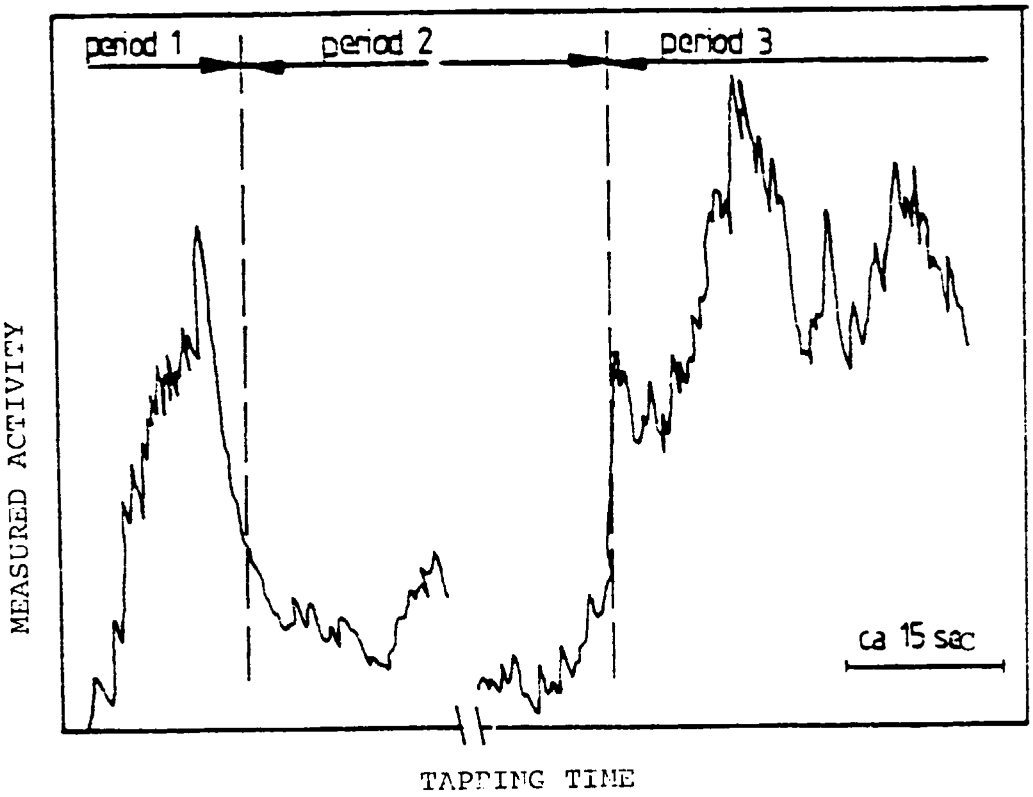
For slag arresting the tapping can be divided into three periods:

Period 1: The first slag will come when the furnace is tilted.

Period 2: During steeltapping slag will entrap during the hole period.

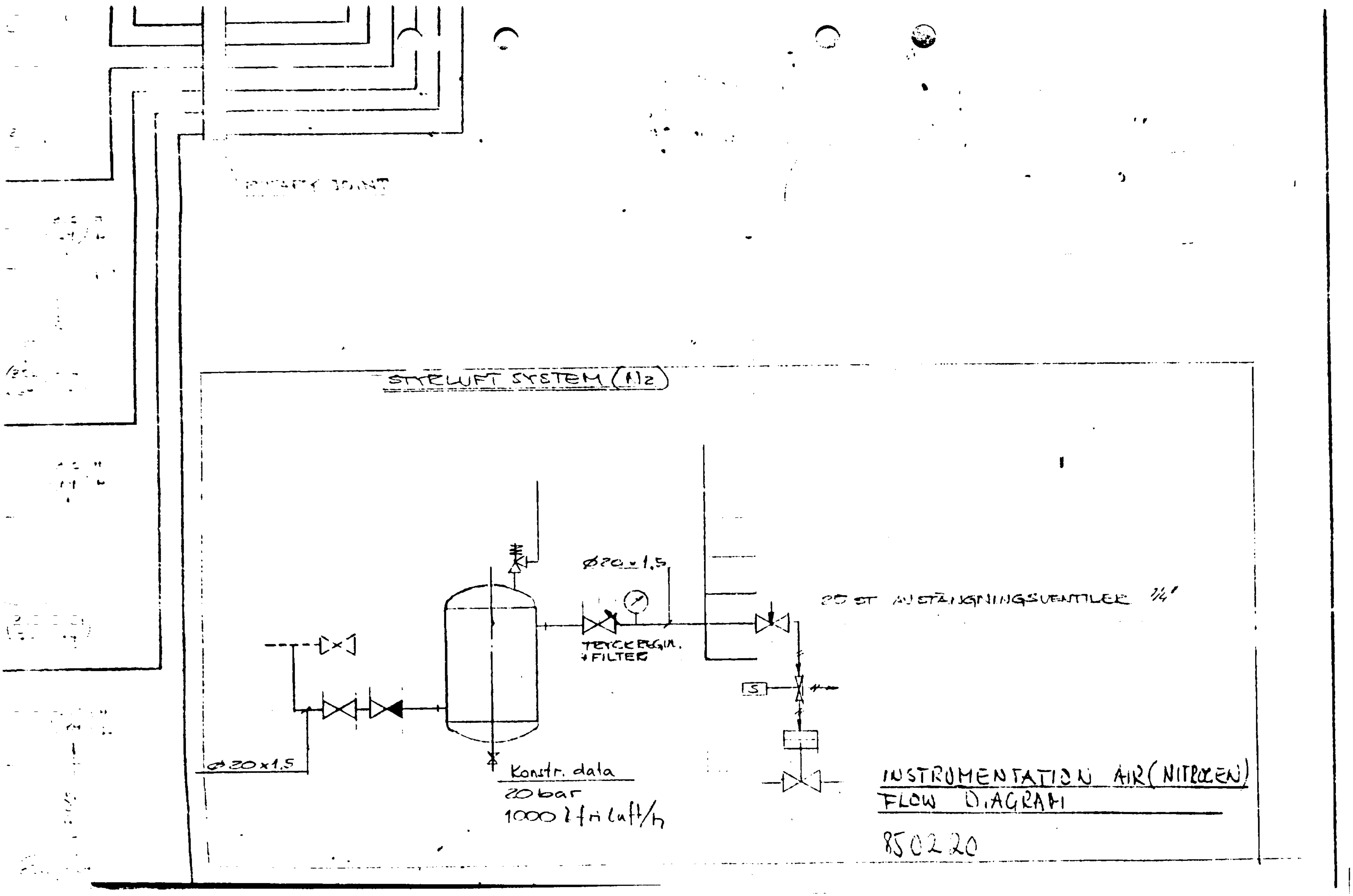
Period 3: At final tapping slag will also flow through the taphole.

The flowrate of slag during tapping has been measured at MEFOS using radioactive tracers. The result is shown in the figure below.



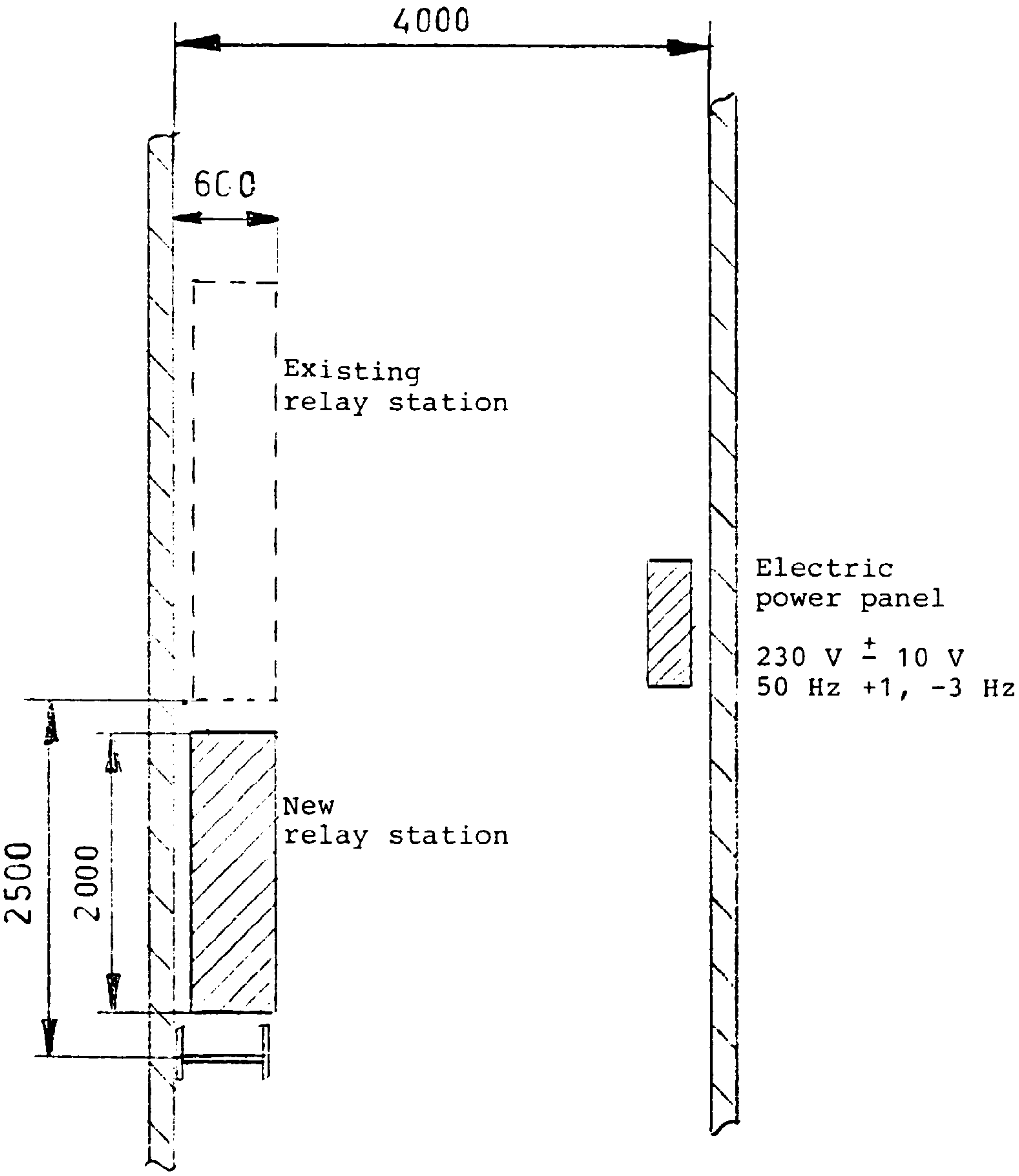
During tapping a vortex is formed above the taphole that results in entrapped slag during the second period. This vortex can be minimized by purging gas via permeable blocks or tuyeres around the taphole.

An important factor when using slag stoppers is the indication of the moment when the taphole should be closed. Such a system has been developed by the company Studsvik Energiteknik AB. The method has proven successful and is for example used at SSAB, Oxelösund.


ROTARY JOINT
STYRLUFT SYSTEM (N2)
Ø20 x 1,5
TRYCKREGL.
+FILTER
25 ST AVSTÄNGNINGSVENTILER ¼'
S
Ø20 x 1,5
Konstr. data
20 bar
1000 l fri luft/h

INSTRUMENTATION AIR (NITROGEN)
FLOW DIAGRAM

850220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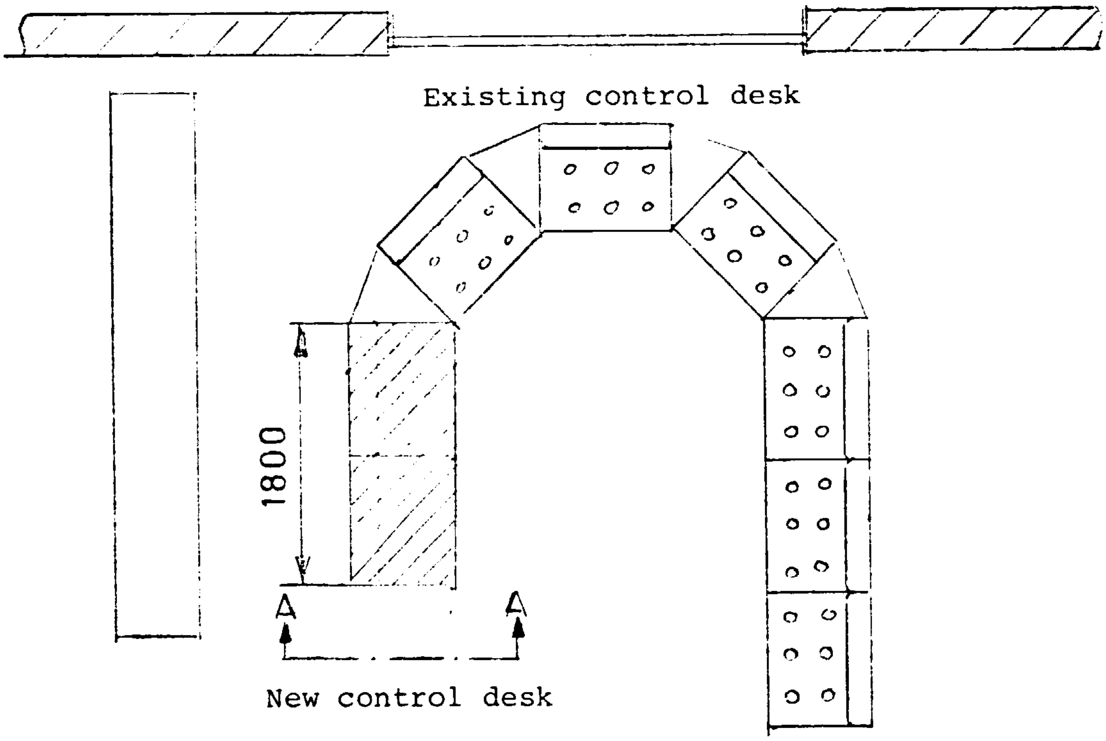
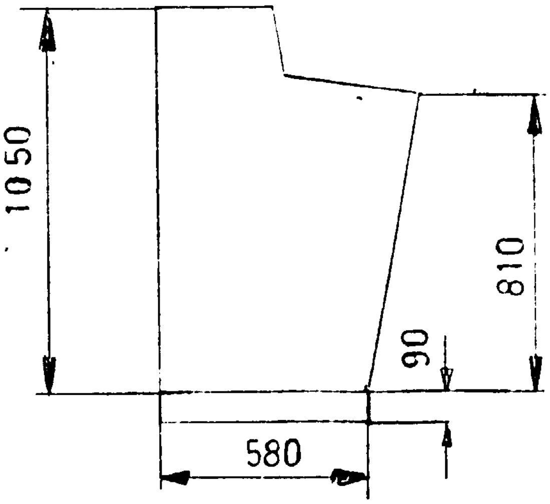
relay station
Electric
power panel
230 V ± 10 V
50 Hz +1, -3 Hz
2500
2000
New
relay station


Existing control desk
1800
A
A
New control desk



A-A

ENGINEERING
INDUSTRIVÄGEN 22, 901 27 UMEÅ
Tfn 090-11 85 00 SWEDEN

VALVE LIST

BORÅRD STEEL PLANT

LD - COMBINED BLOWING

Work no 3811-4104
Side 1 of 7
Issued: 85.01.02
Rev:
Sign: KEB

VALVE No	SYSTEM No	Qty	SERVICE	DESCRIPTION	DIM	CONN TYPE	PN	DESIGN PRESSURE Bar(e)	DESIGN TEMP °C	FLANGE / WELD CONNECTION IN / OUT	LENGTH mm	WEIGHT kg	MATERIAL BODY / SEALING	SUPPLIER / MAKER	VALVE SYMBOL	OPERATING DEVICE	NOTE
PT 11:1		1	Ar,N2	NEEDLE VALVE	15	T	400	20		T 1/2"			SS 2343/	NAF	[illegible]	HAND	THREADS
PT 12:1		1	"	LIKE PT 11:1													
PT 13:1		1	"	"													
HV 14		1	"	BALL VALVE	25	F	25	20		PN25			ACIDPROOF STEEL/	[illegible]	[illegible]	HAND	FLANGE
ZSL,ZSH 14		2	"	CLOSING POSITION BREAKER AND TURNING COMB.													
PT 21:1		1	"	LIKE PT 11:1													
PT 22:1		1	"	"													
PT 23:1		1	"	"													
HV 24		1	"	LIKE HV 14													
ZSL,ZSH 24		2	"	LIKE ZSL,ZSH 14													
PT 31:1		1	"	LIKE PT 11:1													
PT 32:1		1	"	"													
PT 33:1		1	"	"													
HV 34		1	"	LIKE HV 14													
ZSL,ZSH 34		2	"	LIKE ZSL,ZSH 14													
PT 41:1		1	"	LIKE PT 11:1													
PT 42:1		1	"	"													
PT 43:1		1	"	"													
HV 44		1	"	LIKE HV 14													
ZSL,ZSH 44		2	"	LIKE ZSL,ZSH 14													

W = WELDED CONN, F = FLANGED CONN, T = THREADED CONN, P = PRESSED BETWEEN FLANGES

CALOR-CELSIUS ENGINEERING
INDUSTRIVÄGEN 22, 901 27 UMEÅ
Tfn 090-11 85 00 SWEDEN

VALVE LIST

BOKARO STEEL PLANT

LD - COMBINED BLOWING

Work no 3811-4104
Side 2 of 7
Issued: 85 01.02
Rev:
Sign: Keq

VALVE No	SYSTEM No	Qty	SERVICE	DESCRIPTION	DIM	CONN TYPE	PN	DESIGN PRESSURE Bar(e)	DESIGN TEMP °C	FLANGE / WELD CONNECTION IN / OUT	LENGTH mm	WEIGHT kg	MATERIAL BODY / SEALING	SUPPLIER / MAKER	VALVE SYMBOL	OPERATING DEVICE	NOTE
PT 51:1		1	Ar, N_2	LIKE PT 11:1													
PI 52:1		1	"	"													
PT 53:1		1	"	"													
HV 54		1	"	LIKE HV 14													
ZSL.ZSH 54		2	"	LIKE ZSL.ZSH 14													
PT 61:1		1	"	LIKE PT 11:1													
PI 62:1		1	"	"													
PT 63:1		1	"	"													
HV 64		1	"	LIKE HV 14													
ZSL.ZSH 64		2	"	LIKE ZSL,ZSH 14													
PT 71:1		1	"	LIKE PT 11:1													
PI 72:1		1	"	"													
PT 73:1		1	"	"													
HV 74		1	"	LIKE HV 14													
ZSL.ZSH 74		2	"	LIKE ZSL,ZSH 14													
PT 81:1		1	"	LIKE PT 11:1													
PI 82:1		1	"	"													
PT 83:1		1	"	"													
HV 84		1	"	LIKE HV 14													
ZSL.ZSH 54		2	"	LIKE ZSL,ZSH 14													

W = WELDED CONN. F = FLANGED CONN. T = THREADED CONN. D = PRESSED BETWEEN FLANGES

CELSIUS ENGINEERING
INDUSTRIVÄGEN 22, 901 27 UMEÅ
Tfn 090-11 05 00 SWEDEN

VALVE LIST
BOKARO STEEL PLANT

LD - COMBINED BLOWING

Work no 3811-4104
Side 3 of 7
Issued: 85.01.02.
Rev:
Sign: KA

VALVE No	SYSTEM No	Qty	SERVICE	DESCRIPTION	DIM	CONN TYPE	PN	DESIGN PRESSURE Bar(e)	DESIGN TEMP °C	FLANGE / WELD CONNECTION IN / OUT	LENGTH mm	WEIGHT kg	MATERIAL BODY / SEALING	SUPPLIER / MAKER	VALVE SYMBOL	OPERATING DEVICE	NOTE
HV 100		1	Ar	BALLVALVE	50	F	25	20		PN 25			ACIDPROOF STEEL /	Neles	RB15ULF	HAND	FLANGE
PI 101:1		1	″	LIKE PT 11:1													
PT 102:1		1	″	″													
HSV 103		1	Ar	BALLVALVE	50	F	25	20		PN 25			ACIDPROOF STEEL /	Neles	RB15ULF		FLANGE
HY 103		1	″	EL-PNEUMATIC TURNING DEVICE										Neles 131M1Y	RC35R E4		SPOOL 220V DOUBLE-ACTING DEVICE
ZSL, ZSH 103		2		CLOSING POSITION BREAKER AND TURNING COMB.													
HSV 104		1	Ar	LIKE HSV 103													
HY 104		1	″	LIKE HY 103													
ZSL, ZSH 104		2	″	LIKE ZSL, ZSH 103													
PT 105:1		1	″	LIKE PT 11:1													
HSV 106		1	Ar	BALLVALVE	15	F	25	20		PN 25			ACIDPROOF STEEL /	Neles	RB15ULF		FLANGE
HY 106		1	″	EL-PNEUMATIC TURNING DEVICE										Neles 131M1Y	RC35R E4		SPOOL 220V DOUBLE-ACTING DEVICE
ZSL, ZSH 106		2	″	LIKE ZSL, ZSH 103													
HSV 107		1	Ar	LIKE HSV 106													
HY 107		1	″	LIKE HY 106													
ZSL, ZSH 107		2	″	LIKE ZSL, ZSH 103													

W = WELDED CONN, F = FLANGED CONN, T = THREADED CONN, P = PRESSED BETWEEN FLANGES

CALOR-
CELSIUS
ENGINEERING
INDUSTRIVÄGEN 22, 901 27 UMEÅ
Tfn 090-11 85 00 SWEDEN

VALVE LIST

BOKARO STEEL PLANT

LD - COMBINED BLOWING

Work no 3011-4104
Side 4 of 7
Issued: 85.01.02
Rev:
Sign: LB

VALVE No	SYSTEM No	Qty	SERVICE	DESCRIPTION	DIM	CONN TYPE	PN	DESIGN PRESSURE Bar(e)	TEMP °C	FLANGE / WELD CONNECTION IN / OUT	LENGTH mm	WEIGHT kg	MATERIAL BODY / SEALING	SUPPLIER / MAKER	VALVE SYMBOL	OPERATING DEVICE	NOTE
HSV 108		1	Ar	LIKE HSV103													
Hy 108		1	″	LIKE Hy 103													
ZSL,ZSH 108		2	″	LIKE ZSL,ZSH 103													
HSV 109		1	Ar	LIKE HSV 103.													
Hy 109		1	″	LIKE Hy 103													
ZSL,ZSH 109		2	″	LIKE ZSL,ZSH 103													
XV 110		1	Ar	CHECKVALVE	50	P	25	20					STAINLESS STEEL/	PROCESSAB/ ASCO	RK46		
PI 111:1		1	″	LIKE PI11:1													

W = WELDED CONN. F = FLANGED CONN. T = THREADED CONN. P = PRESSED BETWEEN FLANGES

ENGINEERING
INDUSTRIVAGEN 22, 901 27 UMEA
Tfn 090-11 85 20 SWEDEN

VALVE LIST

BOKARO STEEL PLANT

LD - COMBINED BLOWING

Side 5 of 7
Issued: 85.01.02
Rev:
Sign: KB

VALVE No	SYSTEM No	Qty	SERVICE	DESCRIPTION	DIM	CONN TYPE	PN	DESIGN PRESSURE Bar(e)	DESIGN TEMP °C	FLANGE / WELD CONNECTION IN / OUT	LENGTH mm	WEIGHT kg	MATERIAL BODY / SEALING	SUPPLIER / MAKER	VALVE SYMBOL	OPERATING DEVICE	NOTE
HV 200		1	N_2	LIKE HV 100													
PT 201:1		1	"	LIKE PT 11:1													
PT 202:1		1	"	"													
HSV 203		1	N_2	LIKE HSV 103													
HY 203		1	"	LIKE HY 103													
ZSL ZSH 203		2	"	LIKE ZSL ZSH 103													
HSV 204		1	N_2	LIKE HSV 103													
HY 204		1	"	LIKE HY 103													
ZSL, ZSH 204		2	"	LIKE ZSL, ZSH 103													
PT 205:1		1	"	LIKE PT 11:1													
HSV 206		1	N_2	LIKE HSV 106													
HY 206		1	"	LIKE HY 106													
ZSL, ZSH 206		2	"	LIKE ZSL, ZSH 103													
HSV 207		1	N_2	LIKE HSV 106													
HY 207		1	"	LIKE HY 106													
ZSL, ZSH 207		2	"	LIKE ZSL, ZSH 103													

W - WELDED CONN, F - FLANGED CONN, T - THREADED CONN, P - PRESSED BETWEEN FLANGES

CALOR-CELSIUS ENGINEERING
INDUSTRIVAGEN 22, 901 27 UMEA
TEL 090-11 85 00 SWEDEN

VALVE LIST

BOKARO STEEL PLANT

LD - COMBINED BLOWING

Work no 3811-4104
Side 6 of 7
Issued: 85.01.02
Rev:
Sign: KB

VALVE No	SYSTEM No	Qty	SERVICE	DESCRIPTION	DIM	CONN TYPE	PN	DESIGN PRESSURE Bar(e)	TEMP °C	FLANGE / WELD CONNECTION IN / OUT	LENGTH mm	WEIGHT kg	MATERIAL BODY / SEALING	SUPPLIER / MAKER	VALVE SYMBOL	OPERATING DEVICE	NOTE
HSV 208		1	N_2	LIKE HSV 103													
HY 208		1	"	LIKE HY 103													
ZSL ZSH 208		2	"	LIKE ZSL ZSH 103													
HSV 209		1	N_2	LIKE HSV 103													
HY 209		1	"	LIKE HY 103													
ZSL ZSH 209		2	"	LIKE ZSL, ZSH 103													
XV 210		1	N_2	LIKE XV 110													
PI 211:1		1	"	LIKE PT 11:1													
HCV 308		1	N_2 Ar	LIKE HSV 103	80	F	25	20		PN25			STAINLESS STEEL				
HY 308		1	"	LIKE HY 103													
ZSL, ZSH 308		2	"	LIKE ZSL, ZSH 103													
HCV 91		1	N_2, Ar	LIKE HCV 307	25	F	25	20		PN25							
H V92		1	"	LIKE HCV 307	25	F	25	20		PN25							
HSV 90		1	"	LIKE HSV 103	25	F	25	20		"							
HSV 94		1	"	— " —	"	"	"	"		"							

W = WELDED CONN. F = FLANGED CONN. T = THREADED CONN. P = PRESSED BETWEEN FLANGES

ENGINEERING
INDUSTRIVÄGEN 22, 901 27 UMEÅ
Tfn 090-11 05 00 SWEDEN

VALVE LIST

BJÖRKBO STEEL PLANT

LD - COMBINED BLOWING

Work no 3011-4104
Side 7 of 7
Issued: 85.01.02
Rev:
Sign: TA

VALVE No	SYSTEM No	Qty	SERVICE	DESCRIPTION	DIM	CONN TYPE	PN	DESIGN PRESSURE Bar(e)	TEMP °C	FLANGE / WELD CONNECTION IN / OUT	LENGTH mm	WEIGHT kg	MATERIAL BODY / SEALING	SUPPLIER / MAKER	VALVE SYMBOL	OPERATING DEVICE	NOTE
XV 302		1	Ar, N_2	CHECK VALVE	80	P	25	20					STAINLESS STEEL/	PROCESSAB/ DISCO	RK46		
TI 304		1	"	THERMOMETER	15												
PI 305		1	"	LIKE PT 11:1													
HCV 307		1	"	CONTROL VALVE	50	F	25/40	20						NAF	827610	HAND	FLANGE
HCV 310		1	"	CONTROLVALVE	25	F	25/40	20						NAF	827610	HAND	FLANGE
XV 311		1	"	CHECK VALVE	25	P	25	20					STAINLESS STEEL/	PROCESSAB/ DISCO	RK46		FLANGE
HCV 320		1	"	LIKE HCV 310													
XV 321		1	"	LIKE XV 311													
HCV 330		1	"	LIKE HCV310													
XV 331		1	"	LIKE XV311													
HCV 340		1	"	LIKE HCV310													
XV 341		1	"	LIKE XV311													
HCV 350		1	"	LIKE HCV310													
XV 351		1	"	LIKE XV311													
HCV 360		1	"	LIKE HCV310													
XV 361		1	"	LIKE XV311													
HCV 370		1	"	LIKE HCV310													
XV 371		1	"	LIKE XV 311													
HCV 380		1	"	LIKE HCV 310													
XV 381		1	"	LIKE XV311													
PIC 303		1	"	PRESSURE REGULATORS	50	T		20						PEAB/ FISCHER	53078620E		FLANGE

W - WELDED CONN, F - FLANGED CONN, T - THREADED CONN, P - PRESSED BETWEEN FLANGES

Till
Calor-Celsius AB

Offert nr
34-PA-5004.1

Blad nr
1

Pos	Antal	Spec	Pris per enhet
	pcs		
		INSTRUMENTATION AND CONTROL SYSTEM SPECIFICATION:	
1.1		Main line Ar and N_2 PI101, PI201, PI111, PI211	
	4	Manometer type WIKA 2040 Connection: R 1/2" Diameter: 100 mm Range: 0...25 bar	
		PT102, PT105, PT202, PT205	
	4	Pressure transmitter type AEC 200 Connection: 1/4" NPT Output: 4...20 mA Supply voltage: 24V DC Range: 0...40 bar Data sheet: 15-2.62	
	4	3-valve block Data sheet: 14-5.31	
	2	Alarm unit type RMG 19 Input: 4...20 mA Output: 2xrelay Data sheet: 61-6.11	
		PV105, PV205	
	2	Control valve type Masoneilan Camflex II To be clamped between pipework flanges Material: stainless steel DN 1" Dimension data: P_1 18 bar P_2 8 bar T +10...+40°C C_v 3,32	
		PIC105, PIC205	
	2	Electronic controller type Protronic PS Input: 4...20 mA Output: 4...20 mA Supply voltage: 220V 50 Hz Data sheet: 62-5.15	

Till
Calor-Celsius AB

Offert nr
34-PA-5004.1

Blad nr
2

Pos	Antal	Spec	Pris per enhet
	pcs		
		PI102, PI202	
	2	Indicator type Ha 72/240 Input: 4...20 mA Frontframe: 72x72 mm	
		PX105, PX205	
	2	I/P-converter type TEIP Input: 4...20 mA Output: 3...15 psi Power supply: 1,4 bar Data sheet: 18-3.11	
		Total flow FE301	
	1	Orifice DIN 1952 DN 80, PN 40 Material: carbon steel/stainless steel Length: 65 mm Pressure connection: R 1/2"	
		FT301	
	1	Diff-pressure transmitter type AEI 200 Connection: 1/4" NPT Output: 4...20 mA Supply voltage: 24V DC Range: 0...25 mbar Data sheet: 15-2.67	
	1	3-valve block Data sheet: 14-5.31	
		TE301	
	1	Resistance thermometer Pt 100 ohm Connection: R 1/2" Insertion length: 100 mm Diameter: 13,5 mm Material: stainless steel	

Pos	Antal	Spec	Pris per enhet
	pcs		
		TT303	
	1	Measuring amplifier type TEU 6 Input: Pt 100 ohm Output: 4...20 mA Range: 0...100°C Power supply: 220V 50 Hz Data sheet: 11-1.12	
		FX301.1	
	1	Computing unit type TZA 305 Input: FT301 4...20 mA TE301 4...20 mA PT105 4...20 mA Output: 4...20 mA Range: 0...1200 mm^3/h Power supply: 220V 50Hz IP20 Data sheet: 18-5.14	
		FX301.2	
	1	Supply unit type TZN 123 with square root extraction Signal span: 4...20 mA Power supply: 220V 50 Hz Data sheet: 18-8.30	
		FI301	
	1	Indicator type Ha 72/240 Input: 4...20 mA Frontframe: 72x72 mm Scale: 0...1200 mm^3/h	
		FQ301	
	2	Integrator type TZIF 3 Input: 4...20 mA Power supply: 220V 50 Hz Data sheet: 18-1.21	

Till: Calor-Celsius AB

Offert nr: 34-PA-5004.1

Blad nr: 4

Pos	Antal	Spec	Pris per enhet
	pcs	By-pass line N_2	
		PI305	
	1	Manometer typ WIKA 2040 Connection: R 1/2" Diameter: 100 mm Range: 0...25 bar	
		FIT306	
	1	Flowmeter type BGN-E, manufacturer Heinrich Connection: 50 mm Output: 4...20 mA Range: 29...290 m^3/h	
		FI306	
	1	Indicator type Ha 72/240 Input: 4...20 mA Frontframe: 72x72 mm	
		Bottom blowing lines	
		PI12, PI22, PI32, PI42, PI52, PI62, PI72, PI82	
	8	Manometer type WIKA 2040 Connection: R 1/2" Diameter: 100 mm Range: 0...25 bar	
		PT11, PT21, PT31, PT41, PT51, PT61, PT71, PT81	
	8	Pressure transmitter type AEC 200 Connection: R 1/2" Output: 4...20 mA Supply voltage: 24V DC Range: 0...40 bar Data sheet: 15-2.62	

Pos | Antal | Spec | Pris per enhet

pcs

TE302

1 Resistance thermometer Pt 100 ohm
Connection: R 1/2"
Insertion length: 100 mm
Diameter: 13,5 mm
Material: stainless steel

TT302

1 Measuring amplifier type TEU 6
Input: Pt 100 ohm
Output: 4...20 mA
Range: 0...100°C
Power supply: 220 V 50 Hz
Data sheet: 11-1.12

FE10, FE20, FE30, FE40, FE50, FE60, FE70, FE80

8 Orifice DIN 1952
DN 25, PN 40
Material: carbon steel/ stainless steel
Length: 65 mm
Pressure connection: R 1/2

FT10, FT20, FT30, FT40, FT50, FT60, FT70, FT80

8 Diff-pressure transmitter type AEI 200
Connection: 1/4" NPT
Output: 4...20 mA
Supply voltage: 24V DC
Range: 0...25 mbar
Data sheet: 15-2.67

8 3-valve block
Data sheet: 14-5.31

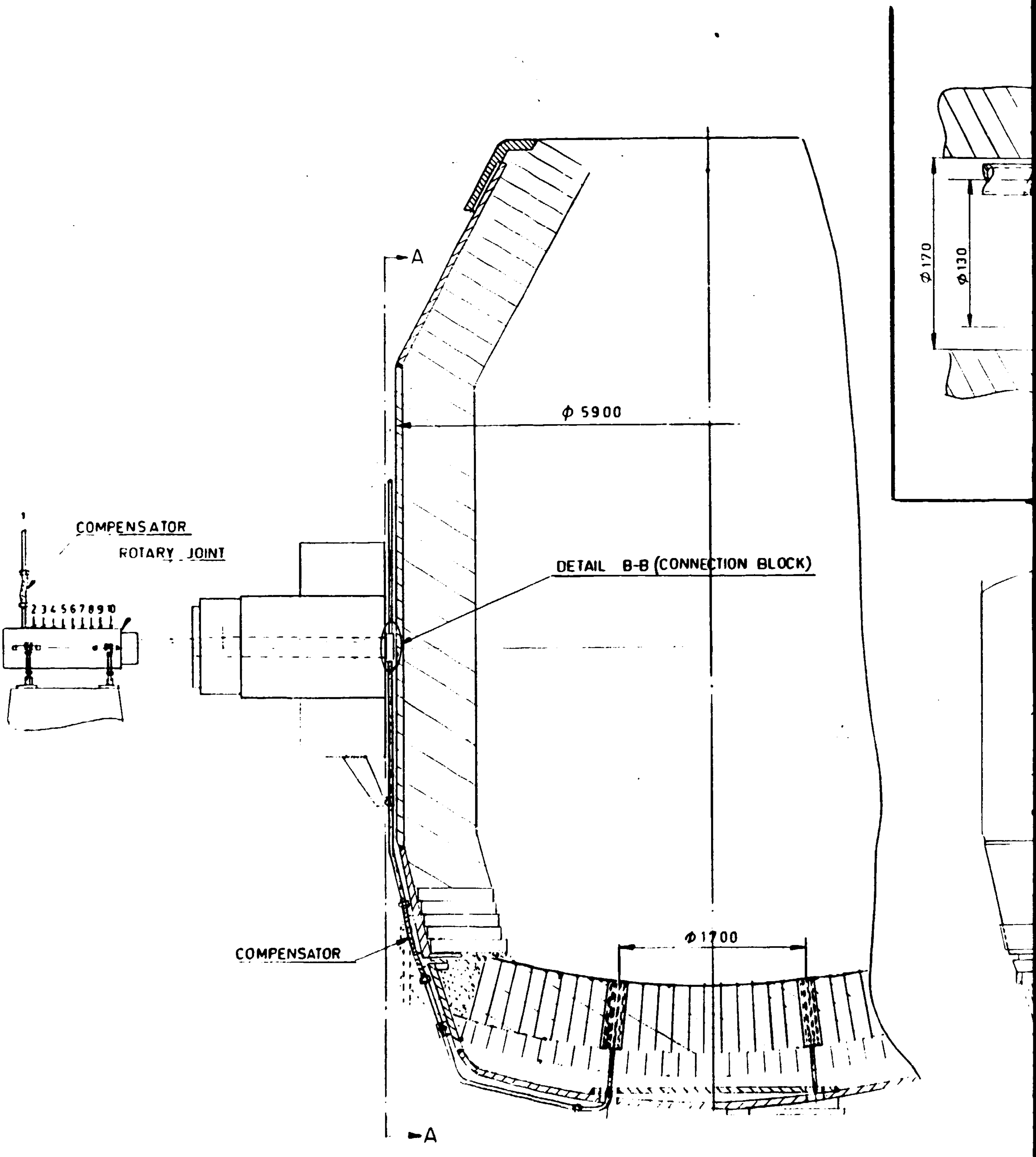
Pos	Antal	Spec	Pris per enhet
	pcs		
		FX10.1, FX20.1, FX30.1, FX40.1, FX50.1 FX60.1, FX70.1 FX80.1	
	8	Computing unit type TZA 305 Input: FT 4...20 mA PT 4...20 mA TT 4...20 mA Output: 4...20 mA Range: 0...120 mm^3/h Power supply: 220 V 50 Hz IP 20 Data sheet: 18-5.14	
		FX10.2, FX20.2, FX30.2, FX40.2, FX50.2 FX60.2, FX70.2, FX80.2	
	8	Supply unit type TZN 123 with square root extraction Signal span: 4...20 mA Power supply: 220 V 50 Hz Data sheet: 18-8.30	
		FIC10, FIC20, FIC30, FIC40, FIC50 FIC60, FIC70, FIC80	
	8	Electronic controller type Protronic PS Input: 4...20 mA Output: 4...20 mA Supply voltage: 220 V 50 Hz Data sheet:	
	8	I/P-converter type TEIP Input: 4...20 mA Output: 3...15 psi Power supply: 1,4 bar Data sheet: 18-3.11	
	4	Alarm unit type RMG 19 Input: 4...20 mA Output: 2xrelay Data sheet: 61-6.11	

Till	Offert nr	Blad nr
Calor-Celsius AB	34-PA-5004.1	7

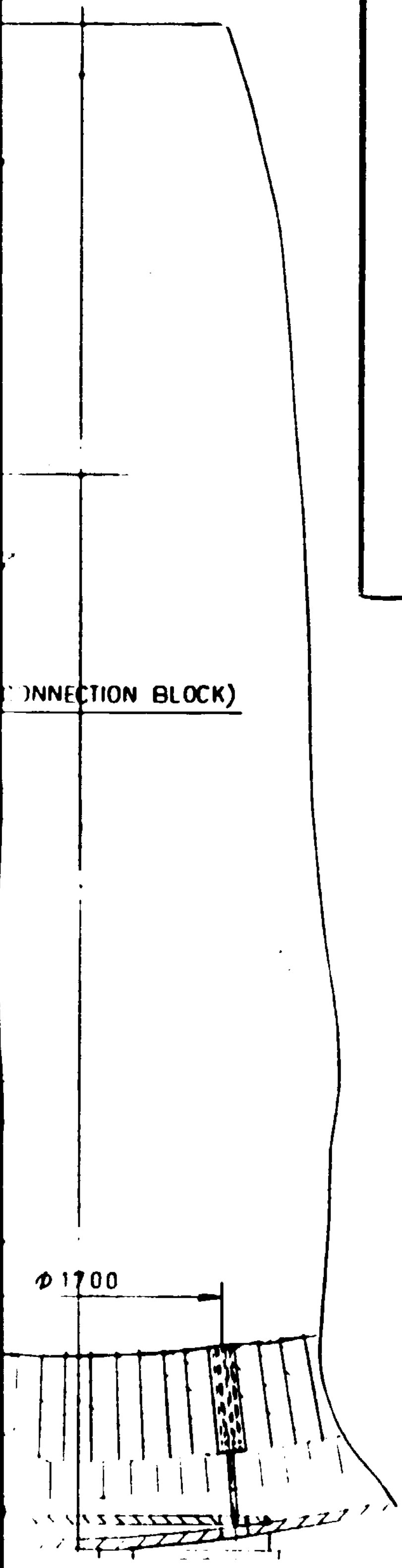
Pos	Antal	Spec	Pris per enhet
	pcs		
		FV10, FV20, FV30, FV40, FV50, FV60, FV70, FV80	
	8	Control valve type Masoneilan Micro Pac To be clamped between pipework flanges Material: stainless steel DN 1" Dimension data: P_1 6 bar P_2 2,5 bar Qmax 96 mm^3/h (Cv 1,01) Q max 200 mm^3/h (Cv 2,3) T +10...+40°C	
		PT13, PT23, PT33, PT43, PT53, PT63, PT73, PT83	
	8	Pressure transmitter type AEC 200 Connection: R 1/2" Output: 4...20 mA Supply voltage: 24V DC Range: 0...40 bar Data sheet: 15-2.62	
		PI13, PI23, PI33, PI43, PI53, PI63, PI73, PI83	
	8	Indicator type Ha 72/240 Input: 4...20 mA Frontframe: 72x72 mm	
		PA13, PA23, PA33, PA43, PA53, PA63, PA73, PA83	
	4	Alarm unit type RMG 19 Input: 4...20 mA Output: 2xrelay Data sheet: 61-6.11	
		Central control room	
	1	Control section 1800 x 800 x 1050 mm including: 10 controllers 12 indicators 2 integrators 4 alarm modules 4 panel switches 26 control lamps	

Pos	Antal	Spec	Pris per enhet	
	pcs			
	1	Relay cabinet including: - alarm units (RMG 19) - power supply (24V DC) - computing units (TZA 305) - terminal, wires and circuit breakers		
2		COMPUTER SYSTEM		
2.1		Hardware		
	1	PCR31, SattCon31, central unit		
	1	ROM30, ROM-memory board		
	1	RAM30, RAM-memory board		
	1	24V2ARC, Power unit för ORG 24		
	4	ZU1, Automatic circuit breaker		
	350	SAK2.5, Terminals connected to interface		
	1	CAB2080, Cabinets containing all items specified above		
	1	MC80, Cassettrecorder with interface		
	1	Printer DEC LA 12 with keyboard		
	1	Netcorrector NET C002		
	1	VT 101 screen with keyboard, digital		
2.2		Standard software		
		SattCon 31 Standard monitor with program options:		
		- PHYS 31, Physical units		
		- TEX 31, Alarm texts		
		- CONT 31, PID-controller modules		
		- LIM 31, Limiter modules		

Pos	Antal pcs	Spec	Pris per enhet
		Spare parts	
	1	Pressure transmitter type AEC 200	
	1	Alarm unit type RMG 19	
	2	Diff-pressure transmitter type AEI 200	
	2	Electronic controller type Protronic PS	
	2	Indicator type Ha 72/240	
	2	I/O-cenverter type TEIP	
	1	Measuring amplifier type TEU 6	
	1	Control valve Masoneilan Micro Pac	
	2	Supply unit type TZN 123 with square root extraction	
	1	Computing unit type TZA 305	
	1	Resistance thermometer Pt 100 ohm	
	1	Integrator type TZIF 3	
		Spare parts, computer system	
	1	SattCon 31	
	1	ROM 30	
	1	RAM 30	
	1	24V5ARC	
	1	PIOB	
	1	PBAD	
	1	PSB	
	1	ICA420	
	1	OCAH420	
	1	IDPG48	
	1	ORG24	
	1	VT101	


COMPENSATOR
ROTARY JOINT
1
2 3 4 5 6 7 8 9 10
A
DETAIL B-B (CONNECTION BLOCK)
Φ 5900
Φ 170
Φ 130
COMPENSATOR
Φ 1700
A

SECTION 1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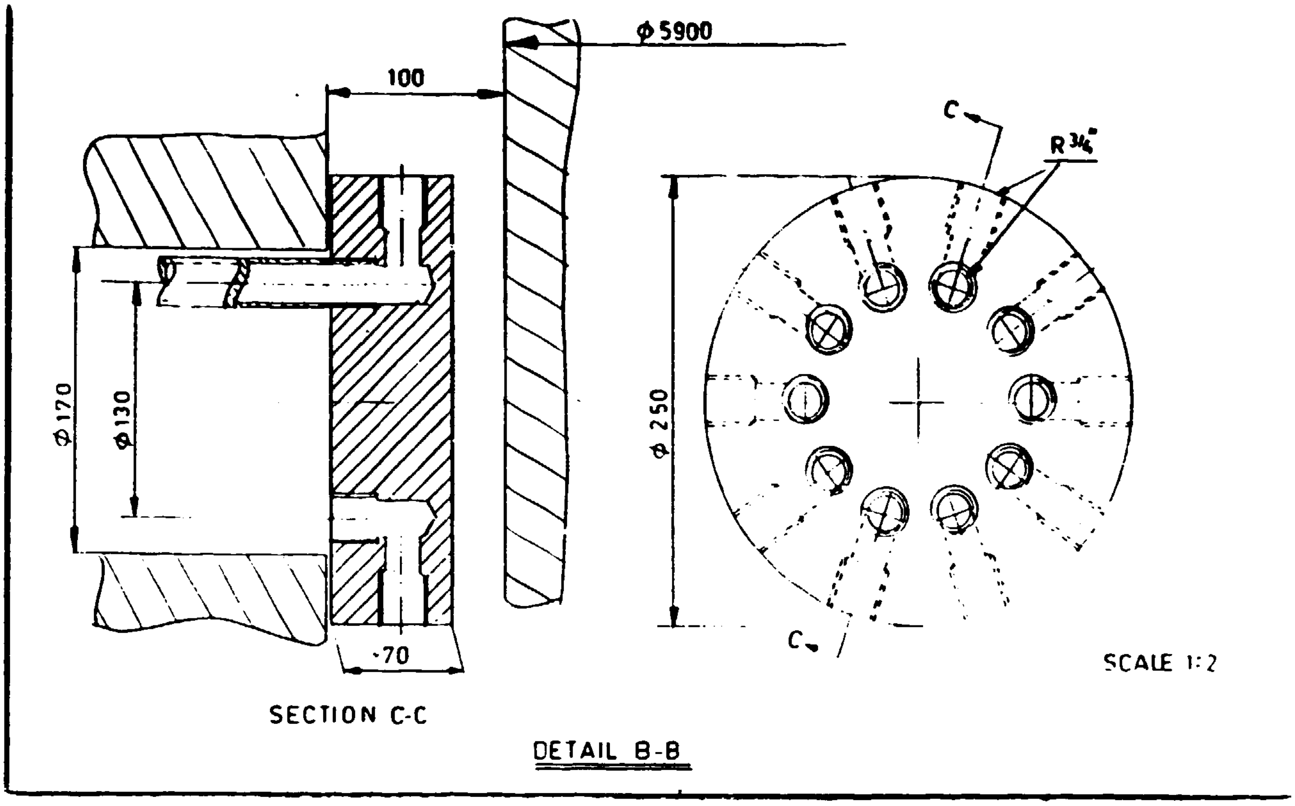
ϕ 1700


ϕ 5900
100
ϕ 170
ϕ 130
70
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R 3/4"
ϕ 250
SCALE 1:2
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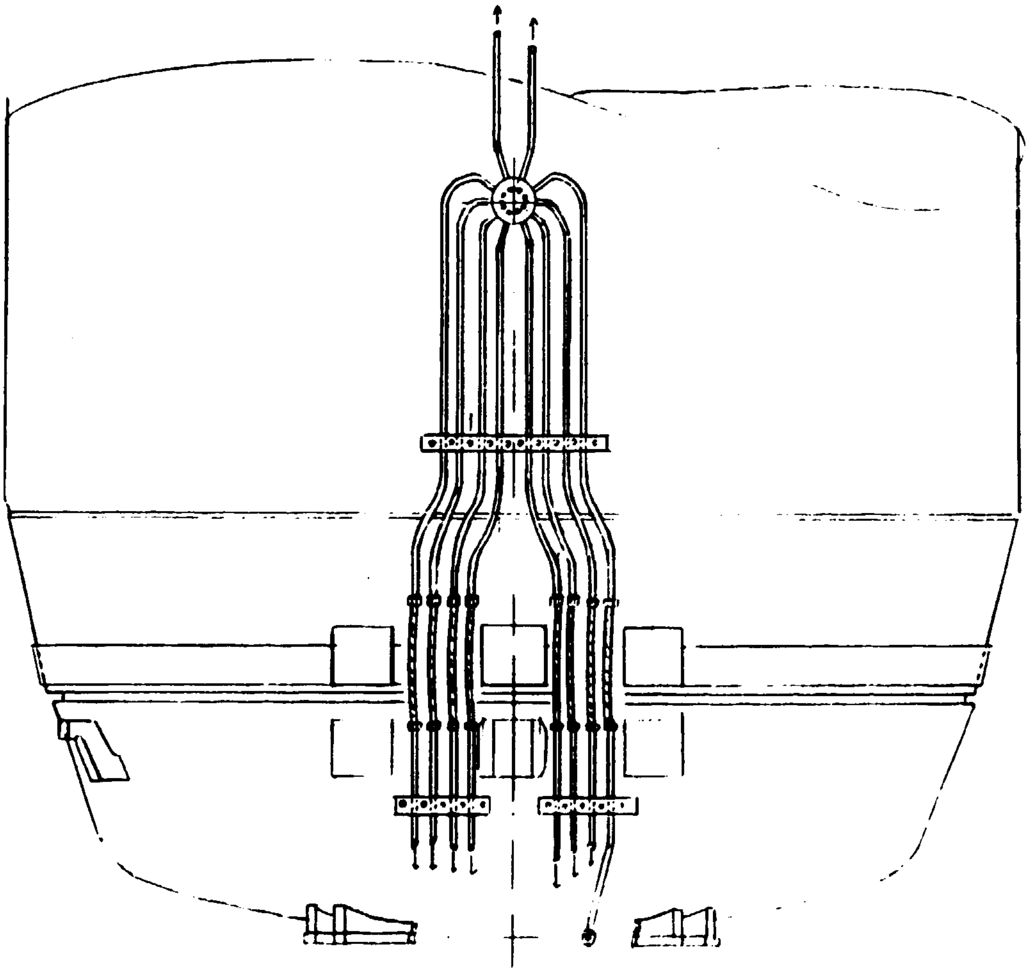
DETAIL B-B

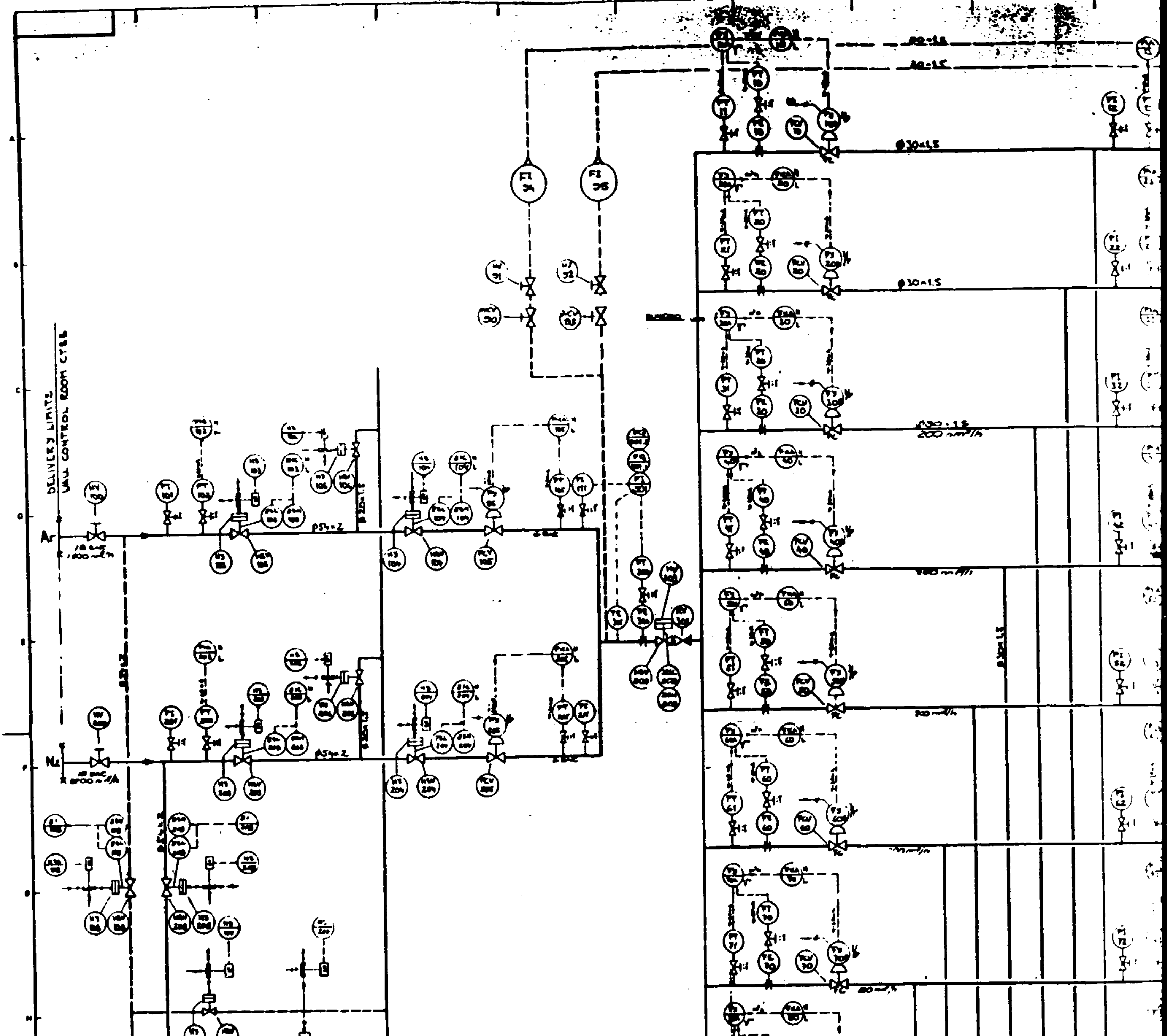


A-A

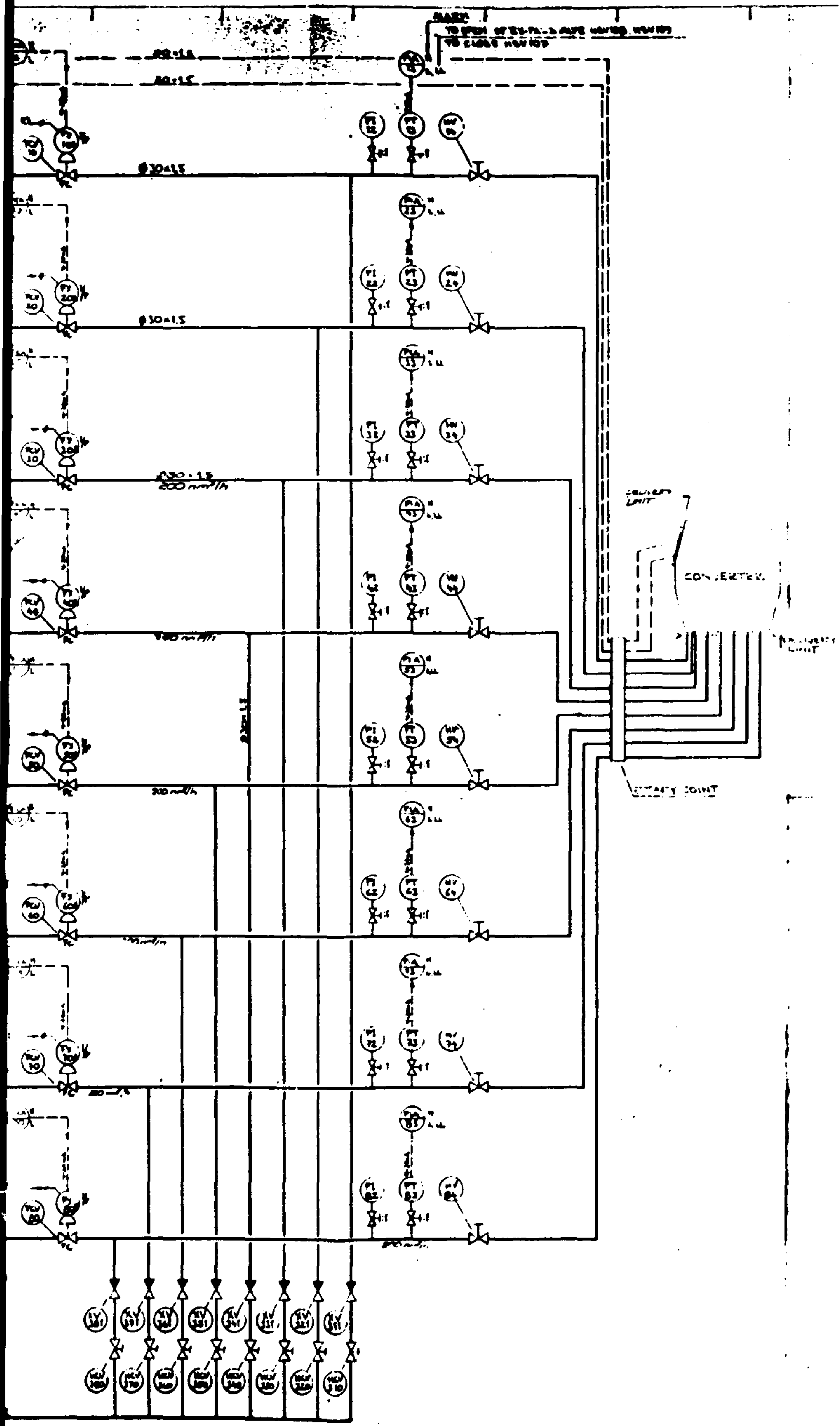
SECTION 2

MEFOS
Rit: U.O.
Dat: 850221
Scale: 1:20 1:2

BOKARO STEELPLANT
PIPE CONNECTION
ROTARY JOINT TO BOTTOM
ELEMENTS


DELIVERY LIMITS
WALL CONTROL ROOM CTBS
Ar
N2
FI 94
FI 95
ø30x1.5
ø54x2
ø20x1.5
200 nm³/h
FIT 306
BY-PASS ø54x2

SECTION 1


ø30×1.5
ø30×1.5
ø30×1.5
200 nm³/h
DELIVERY UNIT
CONVERTER
DELIVERY UNIT
ROTARY JOINT
PT
FT
PI
FV
HV
FC

SECTION 2

☐ CALOR-CELSIUS

☐

BOKARO STEELPLANT

LD-COMBINED BLOWING

FLOW DIAGRAM

GA	EL	

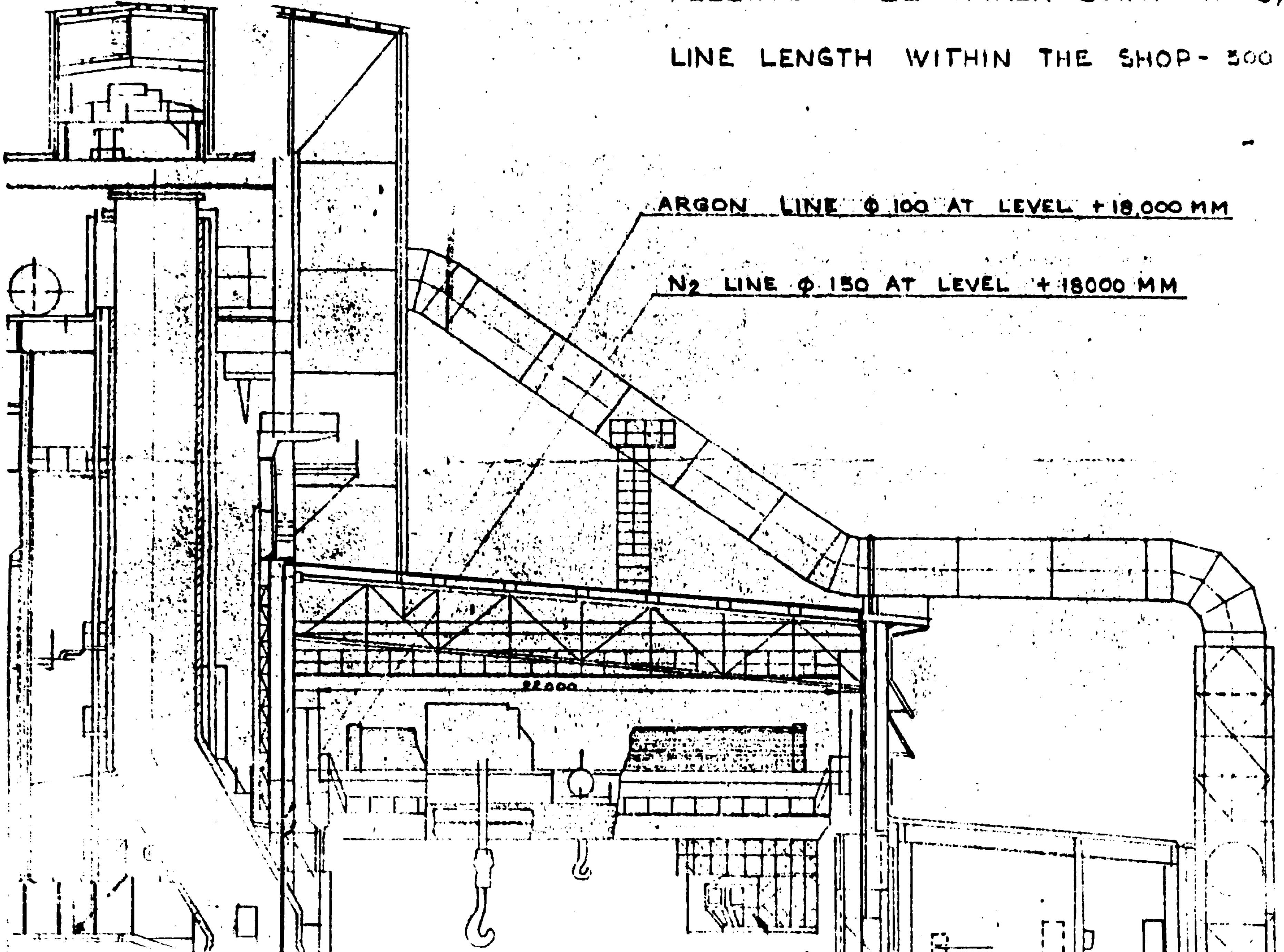
UMEA

3011-4104-1:1

PROPOSED LOCATION OF THE NEW N_2
COMPRESSON FACILITY. TO BE CARRIED
COMPRESSED AIR PIPE LINE ROUTE. TA
FEEDING TO BE TAKEN DOWN AT 9/D, 11/

LINE LENGTH WITHIN THE SHOP- 500 METER

SECTION 1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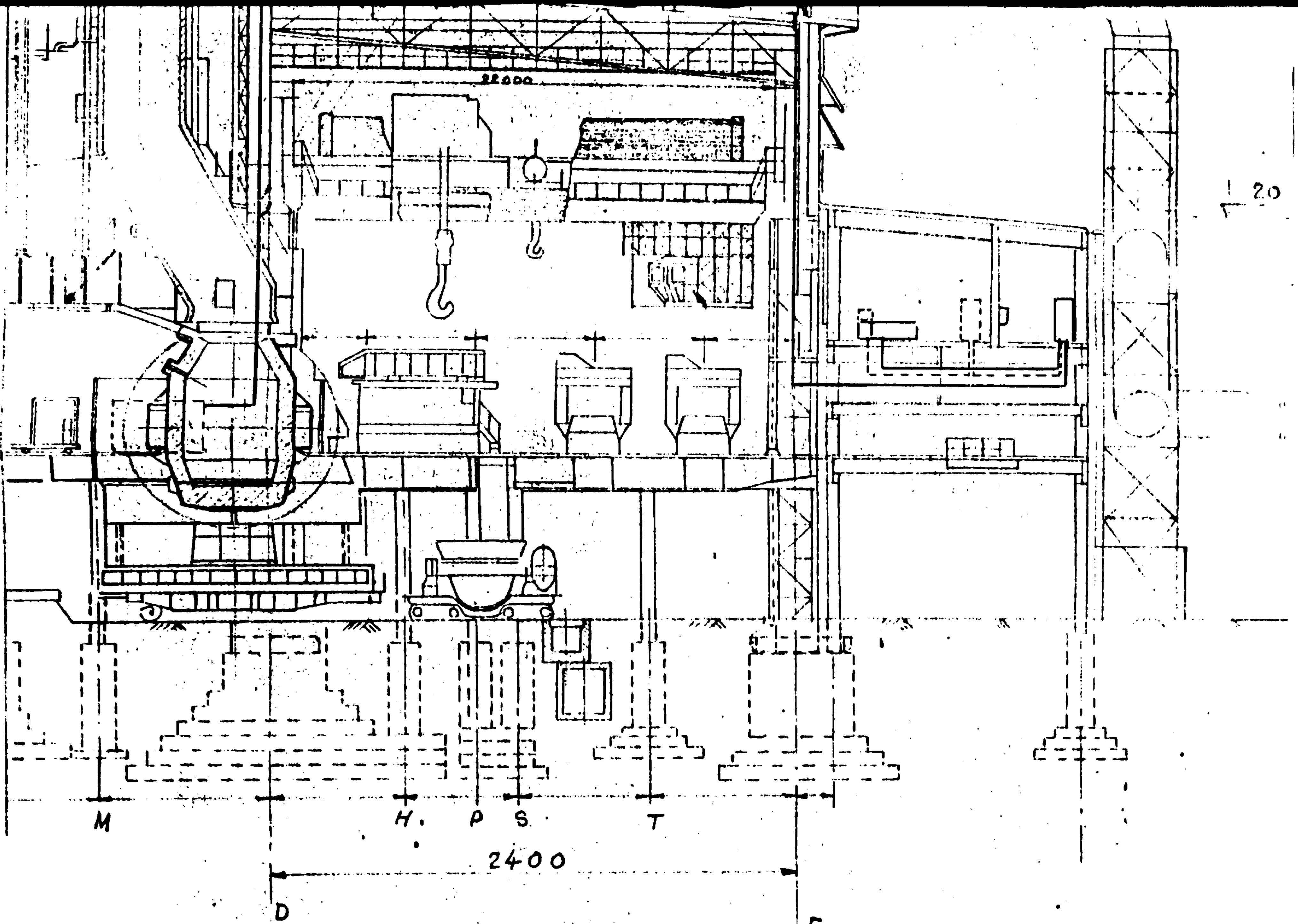
N2 LINE Φ 150 AT LEVEL +18000 MM
22000
20

SECTION 2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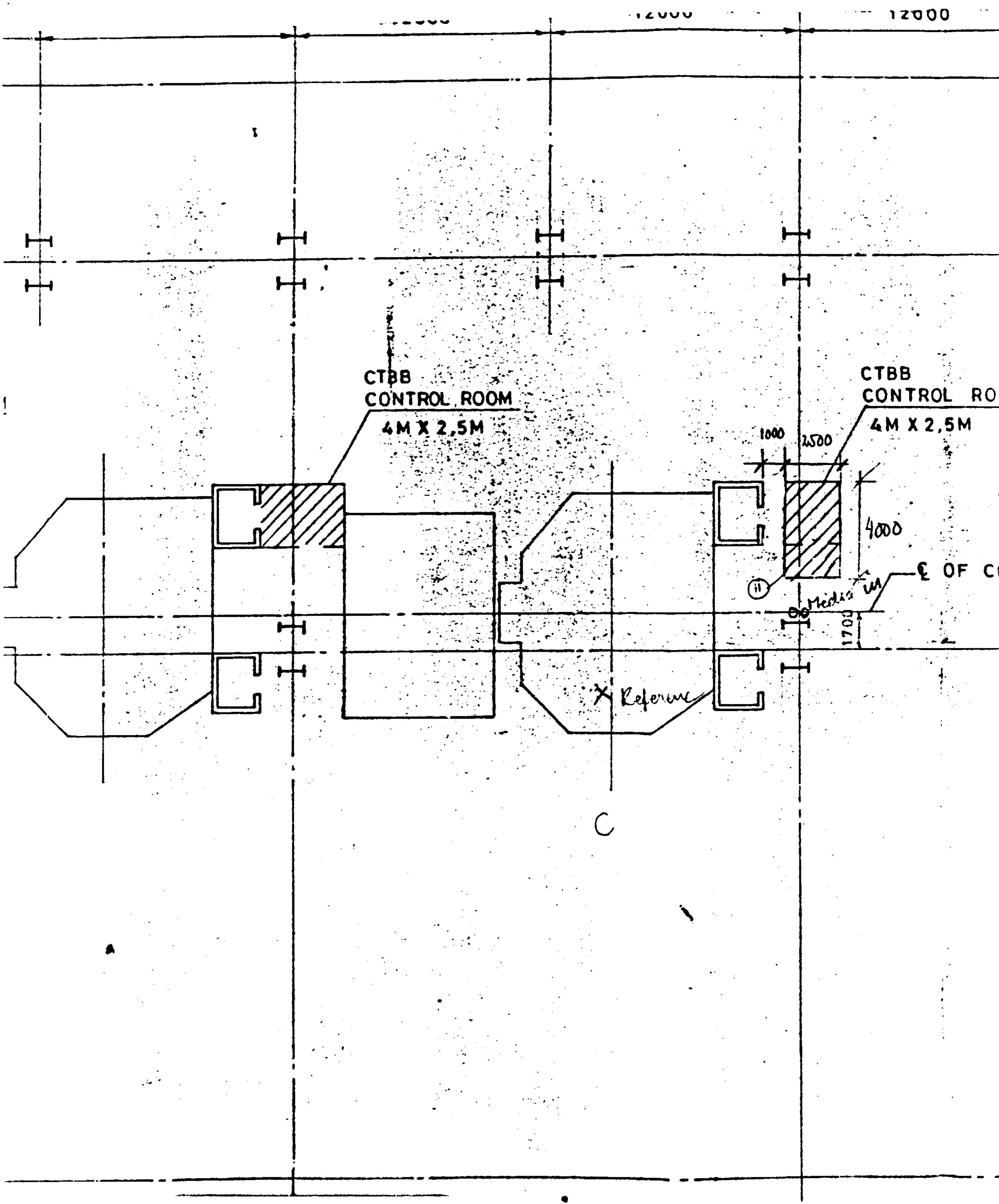
M
H.
P
S
T
2400
D
E

SECTION X-X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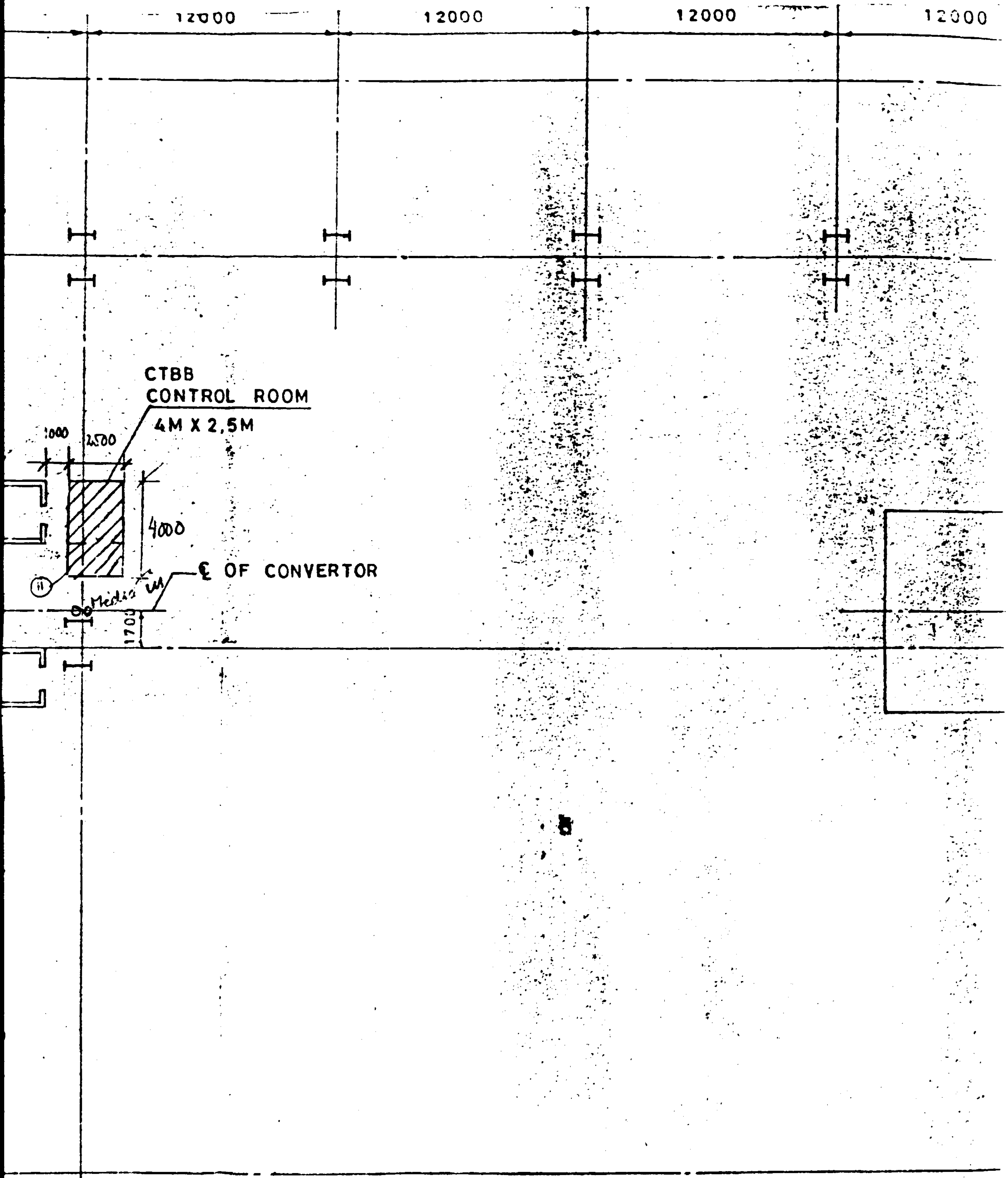
12000
12000
CTBB
CONTROL ROOM
4M X 2,5M
CTBB
CONTROL RO
4M X 2,5M
1000
2500
4000
11
Median
℄ OF C
1700
Reference
C

SECTION 1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12000
12000
12000
CTBB
CONTROL ROOM
4M X 2,5M
1000
2500
4000
11
℄ OF CONVERTOR
Média
1700

SECTION 2

Appendix 3

MEFOS

**METALLURGISKA
FORSKNINGSSTATIONEN**

Forskningsuppgift	Konto	Datum	Reg n
UNIDO/INDIA	4444	1985-03-28	MF85025

SUBJECT: DP/IND/81/036 - CONTRACT NO 84/66 - EXPERT STUDIES

2.4 DEVELOPMENT OF THE 15 T CONVERTER (MEL) FOR PILOT-PLANT OPERATION

by

Mikael Brunner

2.4.1 DEVELOPMENT OF MEL TO PILOT-PLANT

1. The equipment in MEL can be characterized as very good in the following departments:

   - Oxygen plant
   - Converter plant
   - Continuous casting
   - Ingot casting
   - Chemical lab
   - Smelting furnaces

   The equipment is less good in the following department:

   - Melting of metallic charge, that is the cupola furnace.
     Absence of EAF-furnace.

2. The equipment is too big to be used exclusively as pilot-plant equipment. The costs for pilot-plant operations would be far too high.

   Development work must be combined with production in ordinary around-the-clock operations.

3. For production, a suitable steel grade must be selected. The SAIL R/D proposal of stainless steel production is a good choice because the following departments can be well utilized:

   - Converter department
   - Casting department
   - Oxygen plant, with Ar production
   - Laboratory

4. A rough material balance for two cases is presented in the following tables. As can be seen, the need of iron varies considerably.

For MEL a raw material policy maximizing the need of iron could, in principle, be chosen, for example as shown in Table 1. However, this iron, coming from the smelting furnaces would be expensive and not really suitable due to high phosphorus content. At the same time the policy according to Table 1 maximizes the use of primary nickel which is an additional disadvantage costwise.

Table 1 - Material balance 1 ton stainless.

		C	Si	Mn	Cr	Ni	Fe
NiO	91					72	
Ch Cr 55	294	16	10		162		106
Scrap	100			1.5	18	8	74
FeMn 75	17			13			4
Fe	512						512
	1014	16	10	14.5	180	80	696

10% Domestic scrap
90% New alloy

Raw material policy of the type presented in Table 2 can be accomplished by using secondary nickel and steel scrap for the required iron balance.

The raw material policy according to Table 2 calls for an EAF to be installed.

Table 2 - Material balance 1 ton stainless.

		C	Si	Mn	Cr	Ni	Fe
40% scrap	400		2	5	72	32	289
HC Cr 55	196	13	5		108		70
FeNi 24	200					48	152
HC FeMn 70	14			10			4
Fe	185						185
	995	16	10	15	180	80	700

40% Stainless scrap
60% New alloy

5. For pilot-plant operation in converters the input material must satisfy specifications in a wide range. This cannot be done with the smelting furnace and the cupola furnace.

   For pilot-plant operations in MEL an EAF furnace is necessary to provide the converter with specified input material.

6. Stainless steel production as well as pilot-plant operation calls for installation of an EAF in MEL.

   The need of an EAF in MEL must be stressed in a most explicit way.

   With an EAF, MEL can be developed to a major metallurgical unit for stainless production and also to a versatile pilot-plant.

   Without an EAF none of these objectives can be accomplished in an economically suitable manner.

7. The size of the EAF should be 30-35 tons, 4000-4200 mm shell diameter. This size corresponds well with the converters either in LD or CLU/AOD operations.

   The purchase of such EAF is easy today because a great number of such furnaces have been laid down in Europe. Most of these are first class equipment, fully equivalent to new ones.

   The purchase and commissioning should be made by financial support from aid agencies (UNIDO, SIDA etc.). Reference is made to suggestions formulated in discussions with Dr. Nijahwan, UNIDO.

8. For development of MEL to a pilot-plant demonstration unit more instrumentation and process control is necessary, primarily in the converter department. Measurement systems for gases and solids must be included as well as multi input/output process control systems.

9. The developed MEL plant will then have the following activities:

- Stainless steel production in EAF-converter-cc/ingot casting production route.

- Ferro alloy production in smelting furnaces for sale and for use in stainless production.

- Pilot-plant testing of metallurgical processes in intermittent operations.

10. Additional equipment and investments include:

- EAF furnace 30-35 t capacity.

- The oxygen plant completed with argon recovery unit.

- Some modifications of material handling systems

Enclosure 1

Maharastra Electrosmelt Ltd Chandrapur

Visit on December 10, 1984.

Visitors:

Dr. Mikael Brunner, MEFOS
Dr. VA. Venkatadri, SAIL, Ranchi

MEL:

Mr. C.R. Subramaniam, Reginal Manager
Mr. S.S. Hemmady, General Manager (Works)
Mr. A.K. Podey Dy, General Manager (Services)
Mr. Deilip-Shirami, Steelmaking
Mr. S.G. Karande, Quality Control
Mr. Prit Pal Singh, Maintenance

BACKGROUND

The company was established in the late seventies as a steelmaking company based on the process route Electric smelting-BOF-cc/ingot casting. However, the Electric Smelter furnaces were first used for ferroalloy production. Ever since the start of operations FeMn was produced and this production continues on today, although at a reduced rate due to present price structure, (energy), and market situation.

Hot metal production commenced in 1981-92 but was laid down after about 6 months of operation, also due to increased energy costs. The price of electric energy rose from 12 paise to 63 paise per kWh.

The hot metal production for steelmaking was not successful. Hot metal composition varied with subsequent difficulties at the BOF.

The greater part of the equipment is now idle and the company is looking for alternative activities including alloy steel production, (stainless), and research and development work for SAIL.

The purpose of the visit was thus to look at the equipment as a potential stainless steel producer and as a potential pilot-plant for develpoment work.

Oxygen plant

Cry Plants Ltd. UK.
1100 Nm^3O_2/h, 1980 N_2/h
36 m^3 liquid oxygen storage tank
2 x 3000 m^3, 30 bar gaseaus O_2 storage
Ar-outtake connection is included but not Ar tapping facilities

Cupola furnaces

Cold blast furnace, two units, Max 10% steel scrap can be melted besides pig-iron.
1900 mm inside diameter.
Contains about 30 t metal + coke + slagformers when filled.
Capacity: 15 t/h when operated, 150 t/day brutto.
One cupola is operated one day. Tapping 5 t/20 min.
Charging crane 5 t.
Max pieces weight: 70 kg.
Hot metal reciever capacity: 20 t. Reciever gas or oil fired.
Blast pressure 750 mm water gauge.
Cupolas are operated 1 day each with alternation.

P in pig to be melted	0.25-0.30
P in hot metal	0.35
P in ordinary coke	0.18 P

Coke rate in cupola 20% of charge.
(P in coke corresponding to 0.036% pick-up.)
P in HM from ELKEM furnace 0.12%.

CC-plant

Two strands.
Cold tundish 2.5 t capacity.
6 m radius. Curved mould. Concast type.
100 x 100 mm and 120 x 120 mm has been used.
Max dimension: 180 x 220 mm.
Oxygen torque cutting.
Rape-seed oil lubrication, N_2 shrouding.
Handgrinding machines for billets.
Coolingbed, 10 t magnetic lift crane.

Ingot casting

130 kg ingots. Uphill casting.
Double moulds.
About 100 ingots are arranged in 4-5 groups.

Smelting furnace No. 1 (Hot metal producer)

ELKEM-type
200 t HM per day.
2600 kWh/tHM, 3000 kWh/t FeMn
Transformer data see 6 a.

Conversion from FeMn to hot metal included some modification of taphole and "washing out" rests of Mn.

Difficulties during 6 month operation:

- High Mn-content at beginning
- Low tap-temperature
- High and variating Si-content, variations 1.1-3.0%

Gas cleaning. Gas used as fuel.

Casting of FeMn:

a) Sand beds
b) Water cooled moulds

Chemical lab

Philips PU8300 parallel instrument.
15 channels, 1.5 min analyse time.

MEFOS

METALLURGISKA FORSKNINGSSTATIONEN

Appendix 4

Forsknings-uppgift:	Konto:	Datum:	Reg nr:
UNIDO/INDIA	4445	1985-03-28	MF85024

SUBJECT: DP/IND/81/036 - CONTRACT NO 84/66 - EXPERT STUDIES

3.1 PROCESS CONTROL STUDIES - DESIGN DEVELOPMENT OF STATIC CONTROL

by

Nils-Olov Lindfors

Postadress	Gatuadress	Telefon	Telex	Postgiro	Bankgiro
Box 812 S-951 28 Luleå	Arontorpsvagen 1	0920 - 556 40	80482 MEFOS S	61800-9	758-6555

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APPENDIX

3.1.1 INTRODUCTION

A static control model is probably the most valuable tool for achieving an acceptable process control. An improved process control of LD-steelmaking results in a lot of different improvements, not only on productivity but also for quality, refractory wear, etc. This study gives a general description of the design of the static control model used.

3.1.2 BENEFITS OF LD STATIC CONTROL

The major benefits of the introduction of a static control model are:

- the time and accuracy for operators preparing calculations and control work are improved
- logging and record preparation work are eliminated
- hitting rate of the process is increased and the amount of reblown and overblown heats are reduced, resulting in improvements in iron and alloying yields
- productivity is improved due to reduction in downtime and improvements of hitting rate
- control and development work for engineers are much simplified due to the fact that all information is saved in a database, which can be presented in reports or can be studied statistically.

Besides these major benefits, LD process control has a lot of metallurgical and process technical advantages and some of these are summarized below:

- Process control of oxygen flow lance height, (bottom gas flow) and additions result in all operators using the same blowing techniques. Operator mistakes are almost prevented.
- The stopping and variation of iron content in the slag is reduced with an improvement in iron yield.
- Variations in hot metal analysis, hot metal temperature can be overcome more easily since the model calculates the blow and additions according to heat and massbalances.
- An uniformed blowing practice improves also the possibilities of an economical and metallurgical optimization of the process and to improvement of steel quality.
- Computer calculated alloy additions, with consideration to the yield related to steel grades, result in 8-10% less reclassification of steel grades compared to manual alloy calculation.
- LD process control by computer is a demand if and when, continuous casting in sequence is introduced.

3.1.3 MAIN FUNCTIONS OF THE SYSTEM

A schematic picture of this kind of system is given (Appendix 1). The system should be connected to the hot metal stations, the scrap yard and secondary steelmaking stations.

The following main functions are performed:

- data collection
- charge and alloying calculations
- operator guidance and automatic control
- report generation

3.1.3.1 Data collection

No process control can function without an efficient data collection. This is mainly carried out by direct communication between the computer and the process, e.g.; the temperature of the hot metal and the tapping temperature are measured by analog input and evaluated by a sampling algorithm with a digital filter, and the analysis results are fed into the computer by on line connection with the laboratory computers etc. This leads in a minimum of manually input data which improves the reliability of the data.

3.1.3.2 Change and alloying calculations

A typical calculation sequence of a charge is shown in Appendix 2. At first the operator determines the desired amount of scrap by doing a scrap calculation. The next calculation, hot metal calculation, gives the desired amount of hot metal. This calculation is based on the actual scrap mix if the scrap loading is finished, otherwise a predicted scrap mix is used.

Before the blow starts the operator makes the first charge calculation to determine the amounts of oxygen, charge additions and coolant materials. This charge calculation is based on an estimated hot metal analysis.

After start of blow a first alloying calculation is performed in order to give the alloying man the amounts of alloying materials to be scaled. This calculation is based on the desired end point analysis.

When the actual hot metal analysis is transmitted from the laboratory computer the charge calculation is executed to modify the preliminary recommendations. (If sublance is used about 2 minutes before blowend the bath solidus temperature is measured without interrupting the blow. The carbon content is then predicted from the measured solidus temperature. Then the oxygen quantity, and if required, the coolant quantity to be supplied until blow end, are decided by using an extra dynamic control model to attain the aim temperature and carbon content.)

At blowend a sample is sent to the laboratory and the temperature is measured. Depending on accuracy and steel grade the operator either waits for the analysis result or he starts tapping at once. When the analysis result is transmitted the alloying calculation is automatically initiated and the resulting alloy mix is displayed on a terminal at the alloying stand.

When all necessary results from the charge are available a post-charge calculation is made to adapt the static model (and dynamic control model) to the real results. In a similar manner a post-alloying calculation is executed.

3.1.3.3 Operator guidance and automatic control

For practical reasons some of the functions should be operator guided and others computer controlled by means of set point control. However, all automatic controls should be possible to overrule by the operator.

The operator guidance calls for adequate manmachine communication; for example 8-colour terminals in LD control rooms and video display terminals in other stations. The following is a description of how the system normally is used for guidance and control during the main phases of a charge.

Scrap handling

The scaling of scrap is guided by instructions on a terminal in the scrap cranes and the actual weights of the scrap are measured and stored. Deviations between desired and obtained weights of the first scrap qualities are compensated by adjustments in the following scrap qualities in order to get the best possible scrap mixture.

Hot metal handling

At the hot metal stations, terminals are used to guide the operators when they are preparing a hot metal ladle to be charged. The amount of desulphurization agent and the amount of hot metal are displayed. The operator has to make a temperature measurement and initiate a weighing of the ladle before he can use the terminal for the next charge. (The temperature is evaluated by the computer, and the hot metal weight is transmitted to the system from the electronic scale of the crane.) This manner of operation ensures that the furnace operator has the necessary data about the hot metal when he starts the blow.

Charge control during the blow

Once the operator has started the blow, the whole blowing period is automatically controlled by the system. The bath level is determined and the lance height pattern is automatically chosen and controlled. Burnt lime, fluxing agents and cooling agents are automatically scaled and added at different times during the blow, based upon the charge calculation. The converter operator has the option to choose a manual mode of operation and use the system as operator guide during the blow.

Alloying

On the terminal at the alloying stand the end point analysis and the desired crude steel analysis are displayed. The recommended amount of alloying materials is also available. When the actual end point analysis is transmitted from the laboratory the alloying model is automatically started, and the result is immediately displayed on the screen. The operator then has the possibility to make some final adjustments in the alloying mix.

3.1.3.4 Report generation

A computer based process control system gives the possibility to produce automatic reports. The advantage with an automatic report is not so much the amount of data as the quality of the data. The generation of the reports can either be event controlled or operator initiated. Appendix 3 shows an example of reports produced at a swedish steelplant.

Event controlled reports.

There are four reports automatically initiated by events in the process. The first is a status report to the production control computer system, which indicates whether the LD is in the blowing or tapping phase. After each charge two reports are printed on a pre-printed form, namely a charge report and a charge log. The charge report contains information about the charge traditionally found in most steelworks. The charge log is a consecutive log with important events and process variables during the charge. Finally a charge data report is transmitted. This report contains about 500 various data about the charge, which are to be stored in the central computer. These data are combined with data from other parts of the steelworks to produce a production report for each month and for each refractory lining campaign. The data are also available for research and development purposes and for static and dynamic model development.

Operator initiated reports

The operator always has access to updated production statistics reports. These reports contain updated production statistics such as number of charges, average material consumption per tonne steel, average analysis and temperature, time accounting etc. These statistics are aggregated per shift and per week, and are available for the last 54 weeks.

Each of the more than one thousand data stored about every charge can be displayed in a semi-graphic report with values from the last 1500 charges.

3.1.4 MODEL DESCRIPTION

3.1.4.1 Equations

Primarily, the model consists of a heat balance, an oxygen balance, a balance for burnt lime and a mass balance. There is also an equation that gives a desired value for the basicity (SiO_2/CaO) of the final slag, depending on the sulphur input and the desired sulphur content in the steel.

In the primary equations there are unknown values for slag weight, iron content in the final slag, and the oxidation ratio of the iron oxide in the final slag. These values are calculated with "secondary" equation.

The primary equations consists of chemical-physical relationships with some empirical corrections. The equations for calculation of desired slag basicity, iron content in slag and iron oxidation ratio are, on the other hand, derived from statistical data.

3.1.4.2 Use of the equations

When the charge calculations are performed the basic equations are solved to calculated amounts to be charged. In the calculations made at different phases in a charge, the basic equations are grouped together and solved in different ways suitable for the desired results. Each calculation can be made several times as materials are weighed and desired values are exchanged with measured values. This concept makes the model flexible and makes it possible to adapt the model to different plants with different material flow, time relationship between scrap and hot metal weighing etc.

As earlier described, the model is normally divided into four calculations, namely

a) Scrap calculation
b) Hot metal calculation
c) Charge calculation
d) Post-charge calculation

3.1.4.3 Scrap calculationn

The scrap calculation gives primarily the desired amount of scrap, but also the amount of crude steel in the vessel, slag amount, preliminary hot metal amount and predicted scrap analysis. Inputs and outputs of the model, see Appendix 4 and 5.

3.1.4.4 Hot metal calculation

The hot metal calculation is normally made after the scrap is scaled, but it can also be executed before.

The calculated variables are: desired value of agents for desulphurization, slag amount and preliminary desired value of burnt lime. If scrap weighing is finished the scrap analysis is calculated. Inputs and outputs of the model, see Appendix 4 and 5.

3.1.4.5 Charge calculation

The charge calculation is made when the blowing starts, but it can also be made later, e.g., when the hot metal analysis arrives. The values calculated are the desired amounts of oxygen, burnt lime, fluxing material and cooling material. In addition the desired basicity and iron content in the slag, the amount of slag and crude steel in the vessel, the heat loss from the vessel before the charge, the heat deficit in the lining after the charge and the scrap analysis are calculated.

The charge calculation can also be started by entering a predetermined amount of burnt lime.

An estimated sulphur analysis is output, if the desired sulphur content in the steel will be exceeded.

If the charge calculations is run before end of blow the result is stored in two separated positions in the computer. In this way the last usable recommendation from the model is saved, even if the recommended values are changed manually. This is helpful for model development and coefficient adjustment. Inputs and outputs of the model, see Appendix 4 and 5.

3.1.4.6 Post-charge calculation

The post-charge calculation is automatically started, when the first end point analysis or the slag analysis arrives via tele link. When end point analysis arrives the oxygen and heat balances are corrected, while slag analysis also gives correction of burnt lime, iron content in slag and slag weight equations. Inputs and outputs of the model, see Appendix 4 and 5.

3.1.4.7 Off-line model development

The LD system should include facilities for off-line testing of the static model against historical charge data.

In this way it is possible to test modifications in the model without disturbing the on-line system.

3.1.5 DYNAMIC CONTROL MODEL

If the static control model is complemented with sublance the control models and the technique for dynamic control can be summarized as follows:

One or two minutes before the time expected to attain to the amount of blowing oxygen determined by the static model, both the temperature of molten steel and its freezing temperature are measured by sublance without blowing interruption.

The freezing temperature obtained is converted to the corresponding carbon content and the amount of oxygen and, if necessary, the coolant up to blow end are calculated.

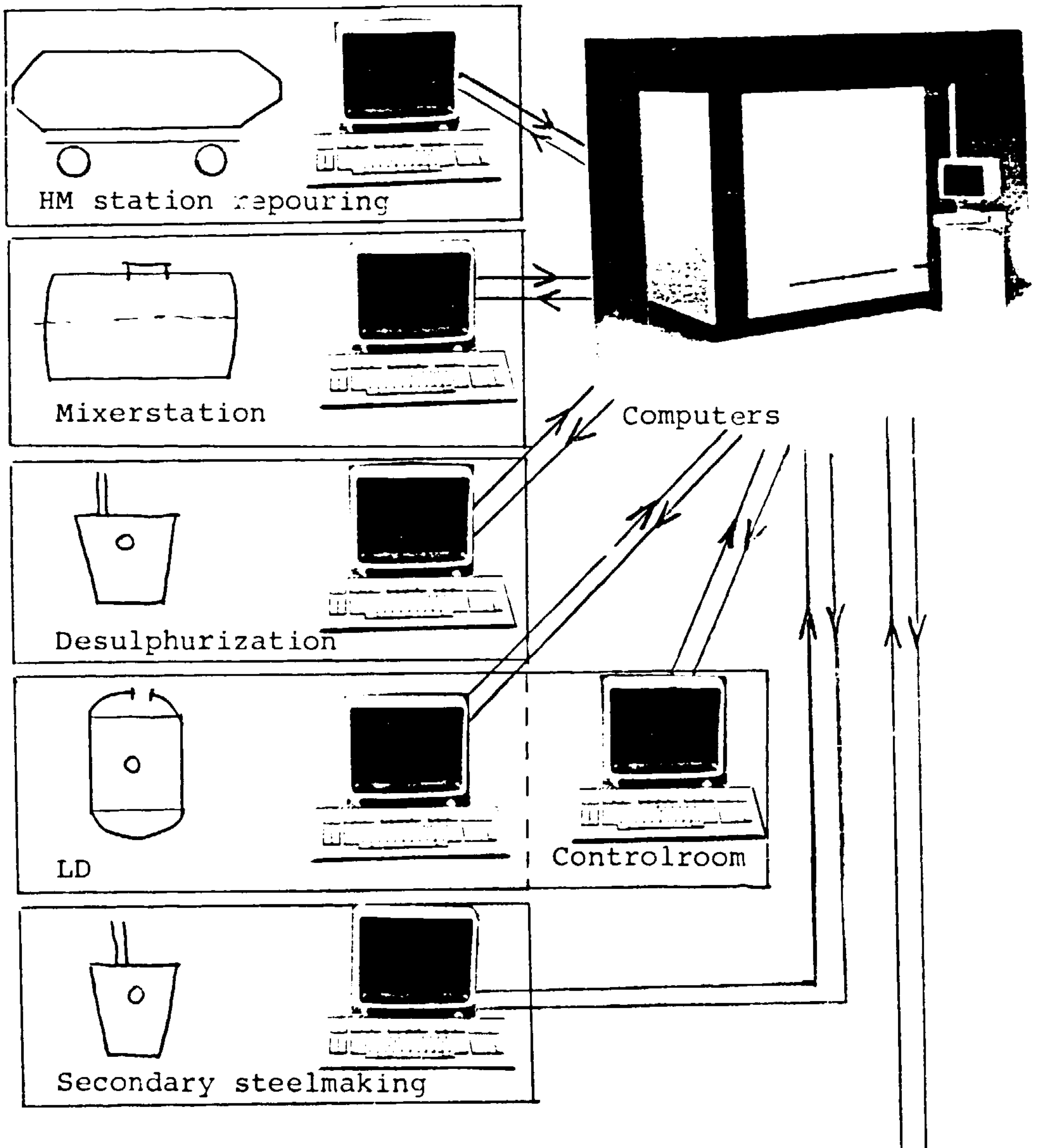
The decarburization and the temperature rise models consist of fundamental equations, regression equations and correction terms using feedback information of preceding charges.

3.1.6 SUMMARY

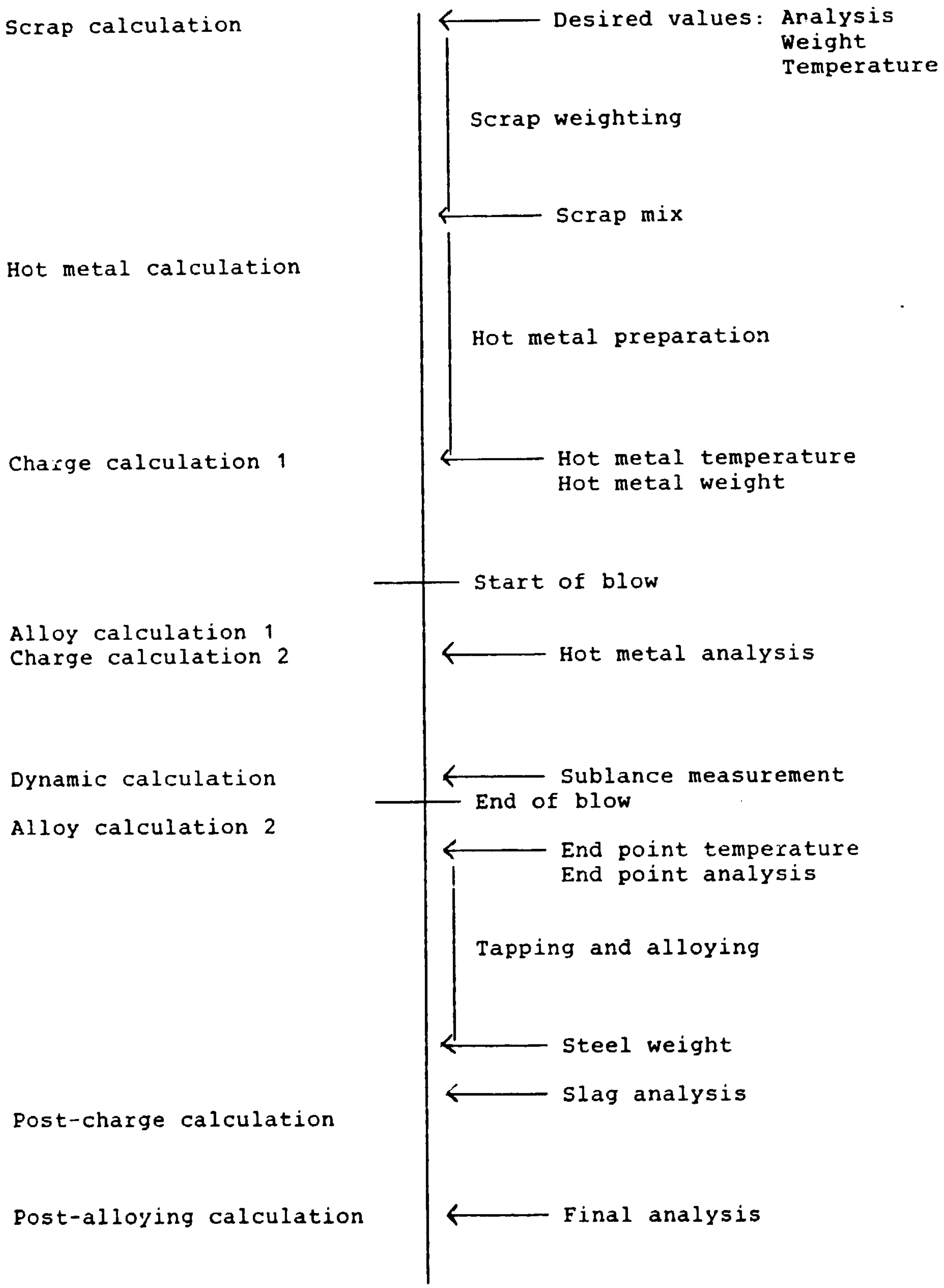
Adoption of a static control model in an LD-plant vastly improves production.

For Indian conditions this also demands a big improvement on instrumentation to support the system with accurate input data. Since these kinds of systems are developed around the world, the cheapest and fastest way is to purchase complete systems for installation in the respective plant.

MAIN CONNECTION TO THE PROCESS


HM station repouring
Mixerstation
Desulphurization
LD
Controlroom
Secondary steelmaking
Computers
Scrapyard

Appendix 2


Scrap calculation
Desired values: Analysis
Weight
Temperature
Scrap weighting
Scrap mix
Hot metal calculation
Hot metal preparation
Charge calculation 1
Hot metal temperature
Hot metal weight
Start of blow
Alloy calculation 1
Charge calculation 2
Hot metal analysis
Dynamic calculation
Sublance measurement
End of blow
Alloy calculation 2
End point temperature
End point analysis
Tapping and alloying
Steel weight
Slag analysis
Post-charge calculation
Post-alloying calculation
Final analysis

Report	Type of report	Initiated	Contents
STATUS REPORT	On-line report to production control computer	Automatically	Information about whether the LD is in the blowing or tapping phase
CHARGE REPORT	Printed	Automatically 3 hrs. after tapping	Traditionally assembled data about the charge
CHARGE LOG	Printed	Automatically 3 hrs. after tapping	Important events and process variables logged in a consecutive way
CHARGE DATA REPORT	On-line report to PRIMDATA central computor	Automatically 3 hrs after tapping	About 500 various charge data
PRODUCTION STATISTICS	Printed	Operator initiated	Aggregated production statistics. A total of 16 different reports can be printed
SEMI-GRAPIC	Display and hard copy	Operator initiated	Any of the logged variables from the last 1500 charges

Appendix 3

INPUTS TO THE MODELS

	Accurancy	Scrap calculation	Hot metal calculation	Charge calcul.	Post charge calcul.
Hot metal					
Weight	$\sigma=\pm 200$ kg			X	X
Pred analysis	C=±0.2 Si=0.1 Mn=0.1 Ti=0.02 V=0.02	X	X		
Pred temp	$\sigma=\pm 15$	X	X		
Actual analysis	C=±0.1 Si=±0.05 Mn=±0.05 Ti=±0.01 V=±0.01			X	X
Actual temp	$\sigma=\pm 5$				
Scrap					
Calculated analysis		X	X	X	X
Weight	$\sigma=\pm 100$ kg		X	X	X
Prechange amount of:					
ore	$\sigma=\pm 20$ kg	X	X	X	X
gunning material		X	X	X	X
tar		X	X	X	X
vessel sculls		X	X	X	X
Perd. amount of Fe in slag	$\sigma=\pm 1,5\%$	X	X	X	X
Actual amount of Fe in slag					X

INPUTS TO THE MODELS

	Accurancy	Scrap calculation	Hot metal calculation	Charge calcul.	Post charge calcul.	
Orded						
Steel weight in ladle		X	X	X	X	
Blow end analysis		X	X	X	X	
Blow end temp		X	X	X		
Actual						
Steel weight in ladle					X	
Blow end analysis					X	
Blow end temp					X	
Pred. amount lime		X				
Model constants		X	X	X	X	1)
Calculated vessle heat loss		X	X	X	X	2)
Pred. Fe-yeald		X	X	X		
Pred. CO_2-analysis in vessle		X	X	X	X	
Actual amount of	σ=±20 kg			X		3)

1) Containing-heats of formation, oxygen need for each element, specific heat, entalphis, theoretical and empirical constants.

2) Empirical-containing, time between heats, tap to tap etc.

3) Step 2 in the change calculation.

Appendix 5

OUTPUTS OF THE MODEL

	Scrap calculation	Hot metal calcul.	Charge step 1	Calculation step 2	Post charge calcul.
Scrap weight	X				
Hot metal weight	X	X			
Slag weight	X	X	X	X	
Steel weight in ladle			X	X	
Lime consumption		X	X		
Dolomitlime consumption			X		
Oxygen consumption			X	X	
Ore consumption			X	X	
Fuel consumption (FeSi)			X	X	
Spar consumption			X	X	
Error oxygen balance					X
Error heat balance					X
Error slag balance					X
Error lime balance					X

MEFOS
METALLURGISKA
FORSKNINGSSTATIONEN

Appendix 5

Forsknings-uppgift:	Konto:	Datum:	Reg nr:
UNIDO/INDIA	4445	1985-03-29	MF85026

SUBJECT: DP/IND/81/036 - CONTRACT NO 84/66 - EXPERT STUDIES

3.2 PROCESS CONTROL STUDIES
- BASIC CONCEPT OF DYNAMIC PC BASED ON MEFOS SYSTEM

by

Nils-Olov Lindfors

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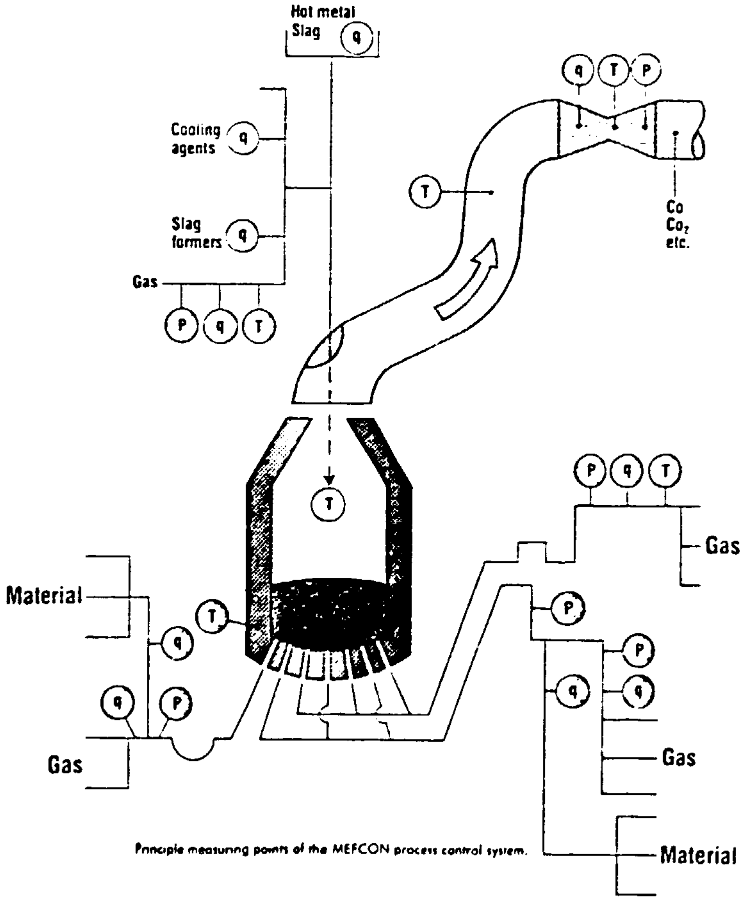
APPENDIX

3.2.1 INTRODUCTION

3.2.1.1 True Dynamic Process Control

True Dynamic Process Control of converters means supervision and control actually based on authentic measured values for the actual heat. Furthermore, the measured values must continously and "without" delay be used as the basis for further calculations and control. This will give a true real-time process control which is able to deal with unforeseen changes at the time they are made. This also means a possibility of true adaptation to sampled results and full utilization of new and up to date sampling techniques.


Hot metal
Slag
q
Cooling agents
q
Slag formers
q
Gas
P
q
T
q
T
P
T
Co
Co₂
etc.
T
P
q
T
Gas
Material
T
q
q
P
P
P
q
q
Gas
Gas
Material

Principle measuring points of the MEFCON process control system.

Figure 1

3.2.1.2 MEFCON Process Control System

MEFCON is:

The foundation for process control systems of the future

- Scientifically based
- Relies on measurements and metallurgical relationships only
- Includes treatment of material injection and additions
- True real time, giving most of the process parameters current values, second by second
- Takes full benefit from, and adapts to, results from up to date sampling systems (sub-lance)
- Enhances the control of the process by improving accuracy, supervision and control possibilites in the gas utility systems
- A real time dynamic heat balance computing software, making it the basis for energy savings and advanced control. MEFCON also estimates the current bath temperature, second by second

- A very good tool for training operators and other staff
- A universal tool for metallurgical research work, a tool that makes process parameters (such as metal analysis) visible (and recordable) at all times during blowing
- The state of the art platform for process control
- Not sensitive to changes made to the process

3.2.1.3 Installation of MEFCON

MEFCON has been developed at The Metallurgical Research Plant (MEFOS) in Luleå, Sweden as a tool for a number of converter processes. Thus it will be adaptable to a wide range of converter processes.

MEFCON will usually supplement any existing process control software rather than enforce a replacement of it, thereby making installation easy. Thus ev. earlier existing investments in functions for operator communication, data base handling and other basics will be fully utilized after a MEFCON installation.

but ...

MEFCON could also be considered (and delivered) as a stand alone turn key process control system, including the necessary computer hardware and/or instrumentation if desired,

3.2.2 GENERAL DESCRIPTION OF MEFCON

The MEFCON package is mainly based on what could be considered as on-line computations of heat- and massbalances. To get appropriate accuracy in these balances, measurements of input and output quantities, or equals, as well as temperatures, should be existent.

3.2.2.1 Massbalance

Main on-line measurements needed are waste gas analysis, waste gas flowrate, media information, enviroment measurements (air, -temp, -pressure, -humidity) and gross weight of dispensers and bins. "Batch" measurements needed are composition of feeded agents, additivees and start composition of metal. The massbalances made are for the elements carbon, oxygen, nitrogen, argon, hydrogen, silicon, manganese, phosphorus, chrome, sulphur, aluminium, magnesium, calcium and compounds of these elements.

Outgoing values in these balances are, for carbon and oxygen, calculated from the waste gas flow and the measured %CO and %CO_2 in the waste gas. The flow rate and analysis give the decarburization rate and hereby a change in the carbon deposit. The difference in oxygen between ingoing O_2 and outgoing O_2 as CO and CO_2, is the oxygen depot forming slag. The oxygen is distributed among the slagforming elements in the metal according to equilibrium and kinetic conditions. The amount of slag compounds formed is used to calculate the slag weight and the slag analysis. What is left of the metal component depots is used in the calculations of the metal weight and the metal analysis.

3.2.2.2 Carbon content calculations

Of main importance is the carbon content determination:

Used ingoing values : Weight of hot metal
Hot metal analysis
Bath temperature
Material additions (lime, scrap, etc)
Process gases (O_2, N_2, Ar, C_3H_8, H_2O)

Used outgoing values : Off-gas flow rate
Off-gas analysis (CO, CO_2)
Dust composition

Calculated value : Carbon analysis in the bath

Calculation principle: A decarburisation rate (dC/dT) is calculated
The decarburisation rate provides a means of evaluating the coal deposit in the bath and also enables oxygen balance values to be calculated. All such values are updated and available continuously:

Accuracy : Supposing no sublance is available, the accuracy of the computed carbon-content in the bath will depend on correct HM-analysis, the accuracy in offgas-analysis- and flowrate measurements
%C = 1-5%   Error < ± 0.10%C

End point estimation : In the end of the blowing the accuracy of the computed carbon-content will increasingly depend on the oxygen yield and at low carbon-contents this oxygen yield entirely determine the carbon-content eliminating measurable errors. Maximum error in this case is visualized in Figure 1.

%C = 0.1 Error ± 0.005%C

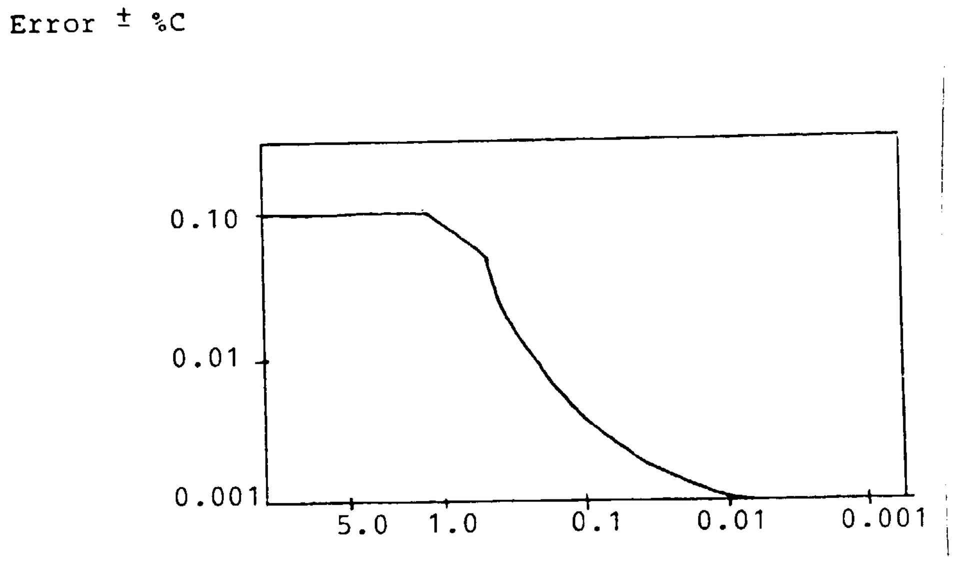
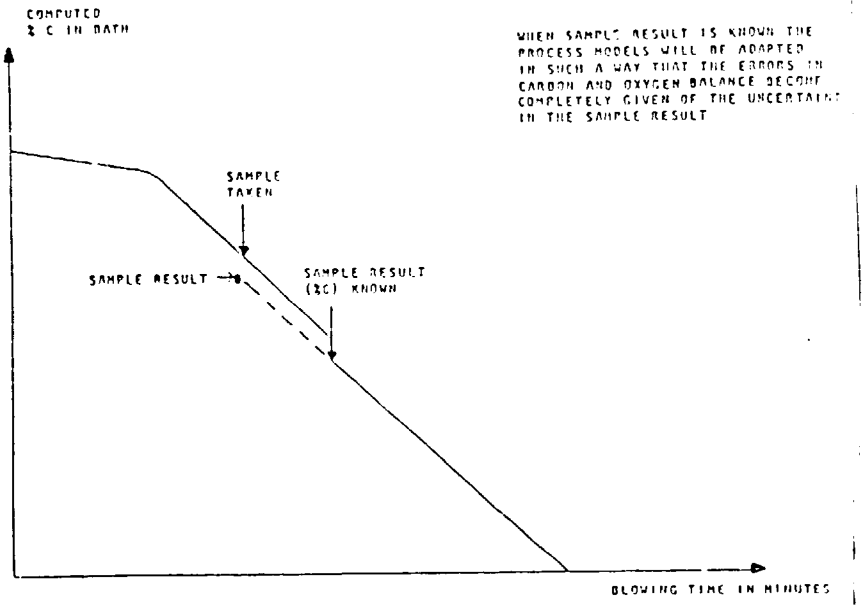


Figure 2

Sublance : The coal deposit and the weight of the bath could be updated by a sublance sample, in such a way that the correct carbon analysis ressults. When taking a sublance sample after 85% of total blowing time, the accuracy will be improved. The principle of carbon analysis updating is visualized in Figure 3.



WHEN SAMPLE RESULT IS KNOWN THE PROCESS MODELS WILL BE ADAPTED IN SUCH A WAY THAT THE ERRORS IN CARBON AND OXYGEN BALANCE BECOME COMPLETELY GIVEN OF THE UNCERTAINTY IN THE SAMPLE RESULT

Figure 3

3.2.2.3 Temperature calculations

Used ingoing values : Weight of hot metal
Hot metal analysis
Ingoing hot metal temperature
Material additions
Process gases

Used outgoing values : Offgas flowrate
Offgas temperature
Offgas analysis

Calculated value : Bath temperature

Calculation principal: Ingoing heat
+ Reaction heat
- Outgoing heat with the gases
- Radiation and other heat-losses
The temperature is given by an enthalpy-equation, after having divided the heat into that going to the slag and that going to the metal

Accuracy	: The bath temperature will be given with a deviation depending on correct HM-temperature, the accuracy in off-gas-analysis and flowrate measurements. $T = T_{actual} \pm 15°C\ (1\sigma)$
Sublance	: The bath temperaure could be updated by a sublance, and thereby improve the heatloss estimation and correct possible measurement errors.

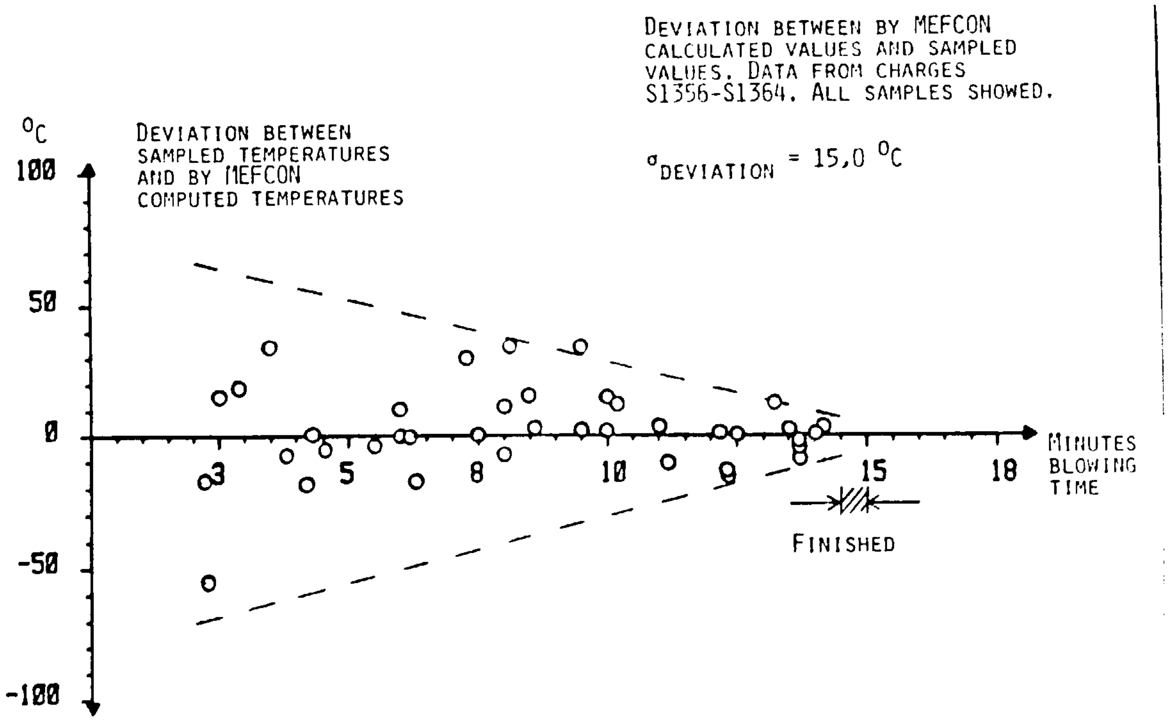
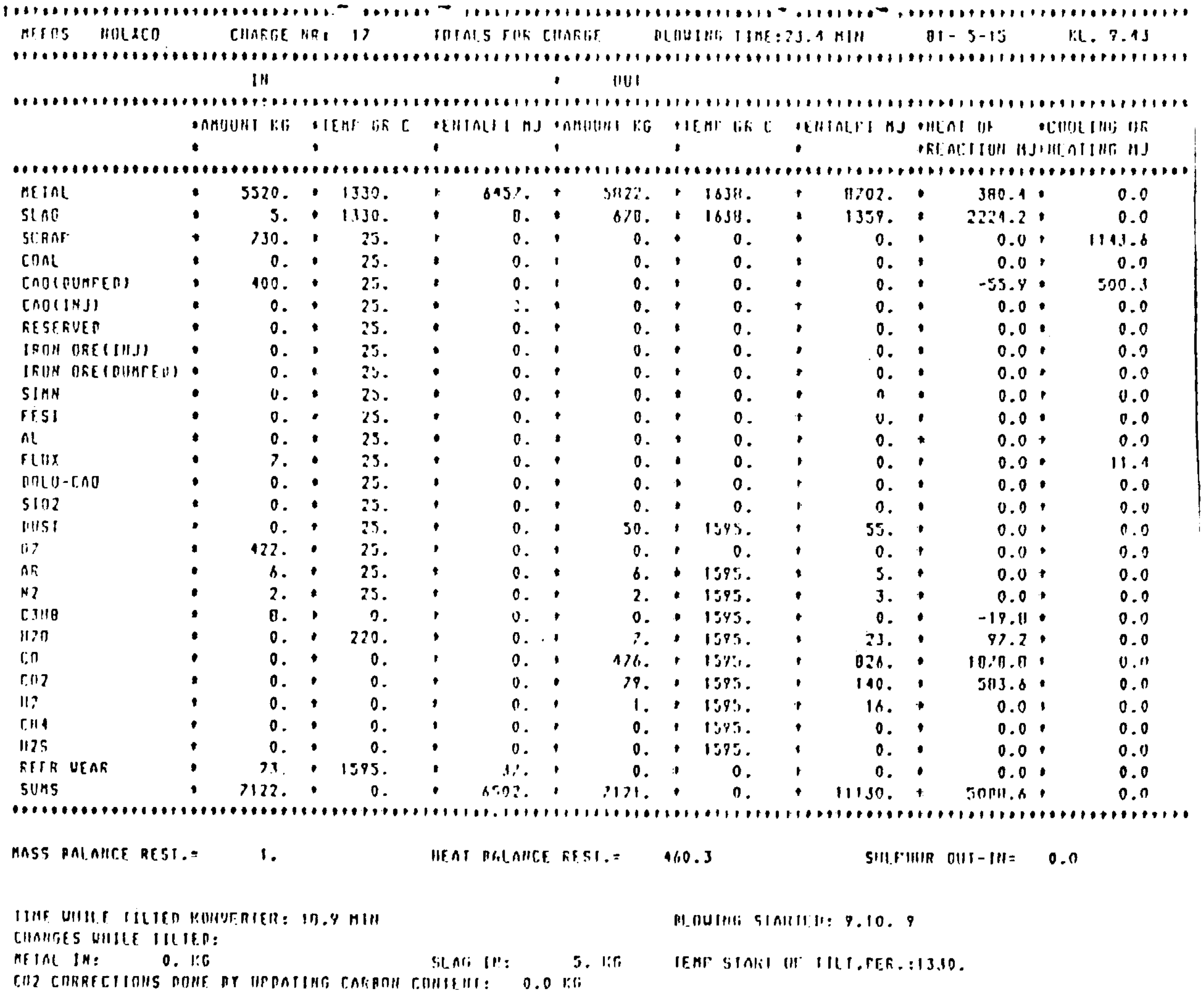


Figure 4

3.2.2.4 Report

A printout of a heat- and massbalance for the current blowing period up to current time can be done anytime, although this is primarily intended to be a report facility for a completed blowing period and thus used only when the converter is tilted.



```
*************************************************************************************************************
 MEFOS   MOLACO        CHARGE NR: 17       TOTALS FOR CHARGE      BLOWING TIME:23.4 MIN       81- 5-15      KL. 9.43
*************************************************************************************************************
                      IN                                   *      OUT
*************************************************************************************************************
                    *AMOUNT KG  *TEMP GR C  *ENTALPI MJ *AMOUNT KG  *TEMP GR C  *ENTALPI MJ *HEAT OF     *COOLING OR
                    *           *           *           *           *           *REACTION MJ*HEATING MJ
*************************************************************************************************************
 METAL              *     5520. *  1330.    *     6457. *     5822. *  1638.    *     8702. *     380.4 *      0.0
 SLAG               *        5. *  1330.    *        0. *      678. *  1638.    *     1359. *    2224.2 *      0.0
 SCRAP              *      730. *    25.    *        0. *        0. *     0.    *        0. *       0.0 *   1143.6
 COAL               *        0. *    25.    *        0. *        0. *     0.    *        0. *       0.0 *      0.0
 CAO(DUMPED)        *      400. *    25.    *        0. *        0. *     0.    *        0. *     -55.9 *    500.3
 CAO(INJ)           *        0. *    25.    *        0. *        0. *     0.    *        0. *       0.0 *      0.0
 RESERVED           *        0. *    25.    *        0. *        0. *     0.    *        0. *       0.0 *      0.0
 IRON ORE(INJ)      *        0. *    25.    *        0. *        0. *     0.    *        0. *       0.0 *      0.0
 IRON ORE(DUMPED)   *        0. *    25.    *        0. *        0. *     0.    *        0. *       0.0 *      0.0
 SIMN               *        0. *    25.    *        0. *        0. *     0.    *        0  *       0.0 *      0.0
 FESI               *        0. *    25.    *        0. *        0. *     0.    *        0. *       0.0 *      0.0
 AL                 *        0. *    25.    *        0. *        0. *     0.    *        0. *       0.0 *      0.0
 FLUX               *        7. *    25.    *        0. *        0. *     0.    *        0. *       0.0 *     11.4
 DOLO-CAO           *        0. *    25.    *        0. *        0. *     0.    *        0. *       0.0 *      0.0
 SIO2               *        0. *    25.    *        0. *        0. *     0.    *        0. *       0.0 *      0.0
 DUST               *        0. *    25.    *        0. *       50. *  1595.    *       55. *       0.0 *      0.0
 O2                 *      422. *    25.    *        0. *        0. *     0.    *        0. *       0.0 *      0.0
 AR                 *        6. *    25.    *        0. *        6. *  1595.    *        5. *       0.0 *      0.0
 N2                 *        2. *    25.    *        0. *        2. *  1595.    *        3. *       0.0 *      0.0
 C3H8               *        8. *     0.    *        0. *        0. *  1595.    *        0. *     -19.8 *      0.0
 H2O                *        0. *   220.    *        0. *        7. *  1595.    *       23. *      97.2 *      0.0
 CO                 *        0. *     0.    *        0. *      476. *  1595.    *      826. *    1878.8 *      0.0
 CO2                *        0. *     0.    *        0. *       79. *  1595.    *      140. *     503.6 *      0.0
 H2                 *        0. *     0.    *        0. *        1. *  1595.    *       16. *       0.0 *      0.0
 CH4                *        0. *     0.    *        0. *        0. *  1595.    *        0. *       0.0 *      0.0
 H2S                *        0. *     0.    *        0. *        0. *  1595.    *        0. *       0.0 *      0.0
 REFR WEAR          *       23. *  1595.    *       37. *        0. *     0.    *        0. *       0.0 *      0.0
 SUMS               *     7122. *     0.    *     6494. *     7121. *     0.    *    11130. *    5008.6 *      0.0
*************************************************************************************************************

MASS BALANCE REST.=        1.              HEAT BALANCE REST.=     460.3              SULFUR OUT-IN=   0.0


TIME WHILE TILTED KONVERTER: 10.9 MIN                              BLOWING STARTED: 9.10. 9
CHANGES WHILE TILTED:
METAL IN:       0. KG                      SLAG IN:       5. KG      TEMP START OF TILT.PER.:1330.
CO2 CORRECTIONS DONE BY UPDATING CARBON CONTENT:    0.0 KG
```

Figure 5

3.2.2 SOFTWARE SYSTEM

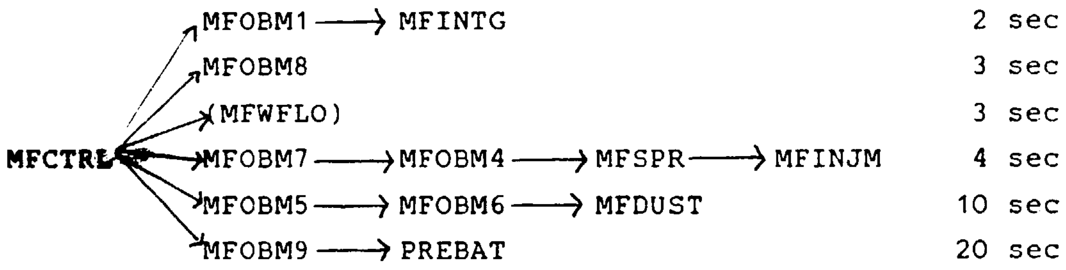
3.2.3.1 What MEFCON consist of

MEFCON consists of the following main modules:

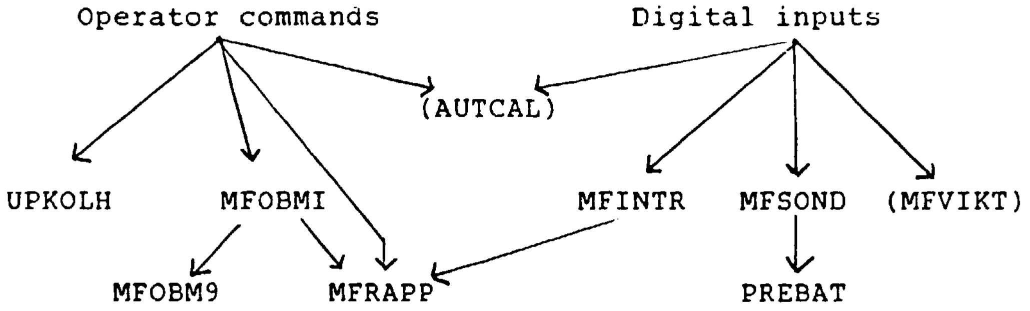
MFOBM1, MFOBM4-MFOBM9, MFINTG, MFSPR, MFINJM, PREBAT, MFDUST, MFCTRL, MFOBMI, MFINTR (two parts) and UPKOHL.

3.2.3.2 Program monitoring

Cyclic programs


MFCTRL
MFOBM1 → MFINTG
MFOBM8
(MFWFLO)
MFOBM7 → MFOBM4 → MFSPR → MFINJM
MFOBM5 → MFOBM6 → MFDUST
MFOBM9 → PREBAT
2 sec
3 sec
3 sec
4 sec
10 sec
20 sec

Event started programs


Operator commands
Digital inputs
(AUTCAL)
UPKOLH
MFOBMI
MFINTR
MFSOND
(MFVIKT)
MFOBM9
MFRAPP
PREBAT

Five different periods are used. Different programs with the same periodicity execute in chains. Within one chain of programs, a program with higher priority starts a program with lower priority. The program with highest priority in every chain is started from the control program MFCTRL.

The different periods are 2, 3, 4, 10 and 20 seconds.

The highest frequency is used for calculations of flows and for accumulations.

3.2.3.3 Block flow-chart description

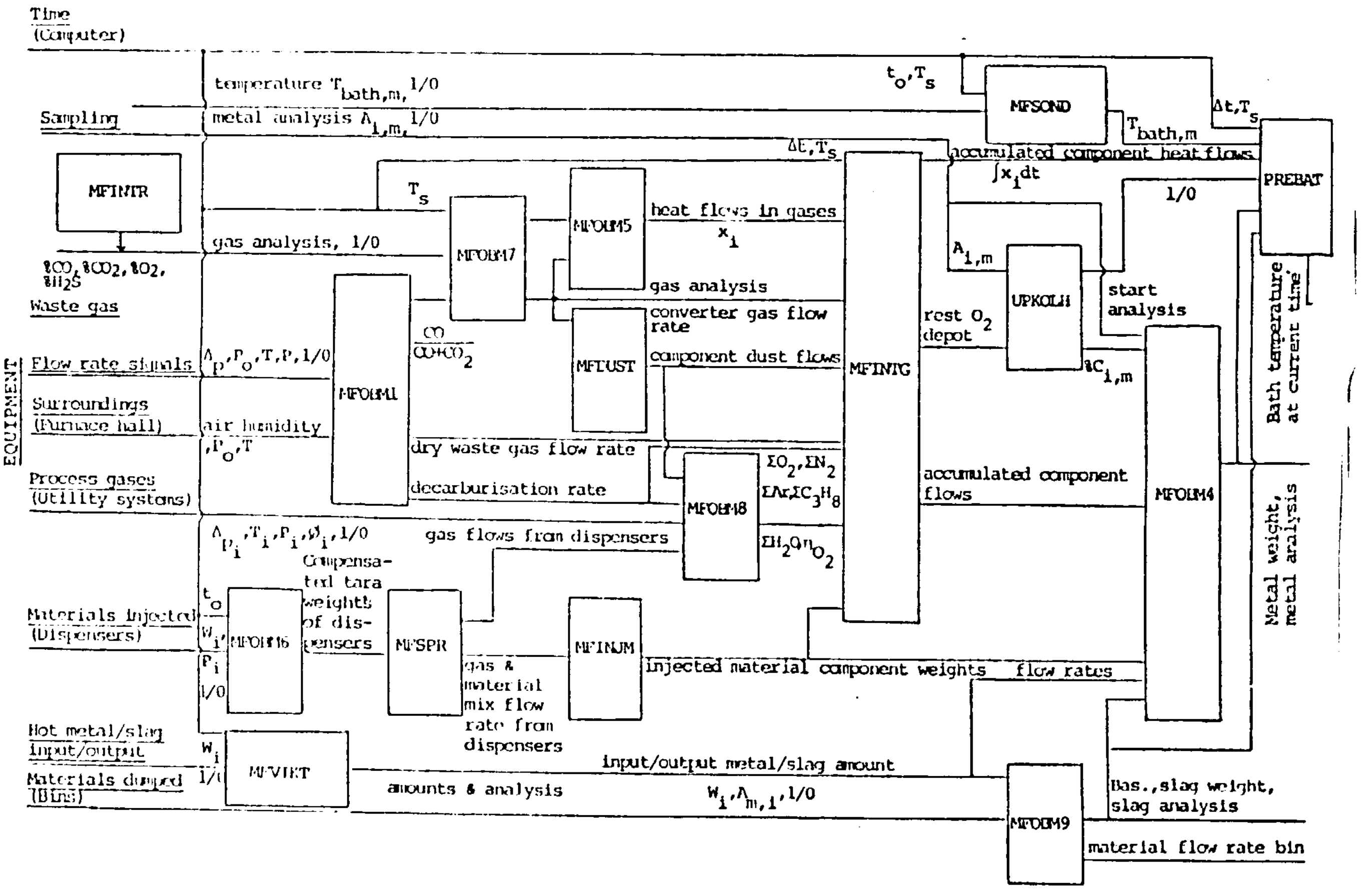

Time
(Computer)
Sampling
temperature $T_{bath,m}$, 1/0
metal analysis $A_{i,m}$, 1/0
MFINTR
%CO, %CO2, %O2, %H2S
Waste gas
EQUIPMENT
Flow rate signals
Surroundings
(Furnace hall)
Process gases
(Utility systems)
Materials injected
(Dispensers)
Hot metal/slag
input/output
Materials dumped
(Bins)
T_s
gas analysis, 1/0
A_p, P_o, T, P, 1/0
air humidity
$, P_o, T$
MFOBM1
MFOBM7
MFOBM5
MFDUST
$\frac{CO}{CO+CO_2}$
dry waste gas flow rate
decarburisation rate
$A_{p_i}, T_i, P_i, \vartheta_i$, 1/0
gas flows from dispensers
Compensated tara weights of dispensers
t_o
W_i,
P_i
1/0
MFOBM6
MFSPR
MFINJM
gas & material mix flow rate from dispensers
W_i
1/0
MFVIET
amounts & analysis
input/output metal/slag amount
$W_i, A_{m,i}$, 1/0
heat flows in gases
x_i
gas analysis
converter gas flow rate
component dust flows
MFOBM8
$\Sigma O_2, \Sigma N_2$
$\Sigma Ar, \Sigma C_3H_8$
$\Sigma H_2O n_{O_2}$
MFINTG
$\Delta t, T_s$
t_o, T_s
MFSOND
$T_{bath,m}$
$\Delta t, T_s$
accumulated component heat flows
$\int x_i dt$
PREBAT
1/0
$A_{i,m}$
UPKOLH
start analysis
rest O_2 depot
$\%C_{i,m}$
accumulated component flows
MFOBM4
Bath temperature at current time
Metal weight, metal analysis
injected material component weights
flow rates
MFOBM9
Bas., slag weight, slag analysis
material flow rate bin

Figure 6

3.2.3.4 Program-to-program communication

Global_communication

This memory resident common area, often referred to as "global" or MFGLOB is used to store data that is passed between several programs or to hold values between program executions. MFGLOB must be integrated in the system so it can be reached from all MEFCON-moduls and it must be protected from write violation from other programs. Start values are read from disc by MFCTRL on system start. The whole area is written to disc by MFCTRL every five minutes. This is done for safety purpose. Each variable in the global area can be reached from the module MFTST.

System_parameters

In addition to the global common area the package uses a function that permits a module to store and fetch a single integer value by a subroutine call. These values can also be reached from the system terminal. This function can be realised by a global common area if the operating system does not contain a simular function for program-to-program communication.

3.2.3.5 Process interface

Analog_values

Analog values, that means analog inputs and outputs, constants and computed values that are of interest for the process are stored in a database table, often referred to as DWT-tables. Reading and writing in these tables are done with subroutine calls.

Digital signals

Digital signals, input and output are stored in two database tables often referred to as DI and DO-tables. There must be a function that allows a program to be immediately (within one second) scheduled for execution when the status of the digital input has changed. Reading and writing in these tables are done with subroutine calls.

3.2.3.6 Operating system interface

The MEFCON package uses system dependent real time functions. These functions are in fact subroutine calls to the operating system. The subroutine names always have the character $ (dollar) in them. The user-operating-system should have, in some meaning these functions.

3.2.3.7 Operator communications

The MEFCON-package communicates with two independent visual display units (VDUs) in its original version and one alarm/message typewriter. Appendix 1 shows examples on how data graphically can be presented, for example overview pictures with dynamically updated data, time-graphs etc.

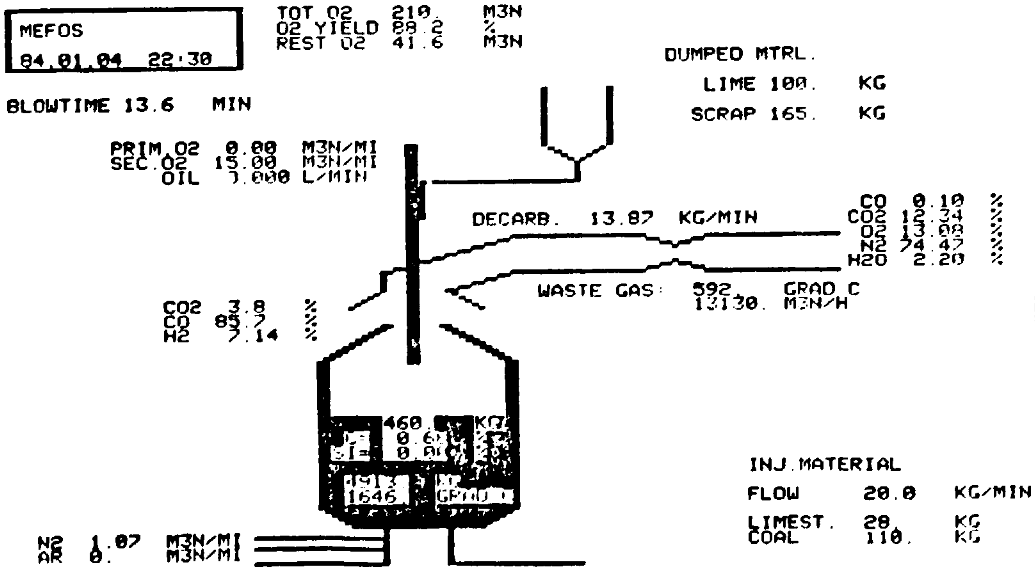

MEFOS
84.01.04 22:30
TOT O2 210. M3N
O2 YIELD 88.2 %
REST O2 41.6 M3N
DUMPED MTRL.
LIME 100. KG
SCRAP 165. KG
BLOWTIME 13.6 MIN
PRIM.O2 0.00 M3N/MI
SEC.O2 15.00 M3N/MI
OIL 0.000 L/MIN
DECARB. 13.87 KG/MIN
CO 0.10 %
CO2 12.34 %
O2 13.08 %
N2 74.47 %
H2O 2.20 %
WASTE GAS: 592. GRAD C
13130. M3N/H
CO2 3.8 %
CO 85.7 %
H2 7.14 %
460. KG
0.6
0.0
1646
GRAD
INJ.MATERIAL
FLOW 20.0 KG/MIN
LIMEST. 28. KG
COAL 110. KG
N2 1.07 M3N/MI
AR 0. M3N/MI

Figure 7

3.2.4 FUNCTIONAL SPECIFICATION OF THE MAIN S/W MODULES

3.2.4.1 MFOBM1

Functions

1 Signal processing to handle cleaning of waste gas flow rate equipment (blowing of impulse pipes), two lines

2 Calculation of static pressure at the place for the flow rate measurement equipment, two lines

3 Computation of air humidity

4 Compensation of known air inlet to analysed gas composition for plants with multi waste gas cleaning lines

5 Waste gas flow rate calculation
5.1 Wet waste gas flow rate corrected for static pressure and thermal expansion, but not corrected for actual composition
5.1.1 Bag filter line
5.1.2 Wet venturi line
5.2 Calculation of waste gas densities
5.2.1 Calculation of dry gas density
5.2.2 Density of real gas composition
5.3 Correction of gas flow rate for actual density

6 Dry waste gas flow rate & flow rate of H_2O in waste gas
6.1 Flow rate of H_2O in waste gas
6.2 Flow rate of dry waste gas

7 Calculation of decarburization rate

8 Calculation of desulphurization rate

9 Calculation of the ratio %CO/(%CO+%CO_2) in converter gas

9.1 Kmol C/h in converter gas components including dust

9.2 Kmol O_2/min in converter gas components excluding dust

9.3 Kmol O/min reacting with C in converter gas

9.4 m^3n CO+CO_2/h in converter gas

9.5 Calculation of the ratio %CO/(%CO+%CO_2)

9.6 Supervision of the computed %CO/(%CO+CO_2) ratio

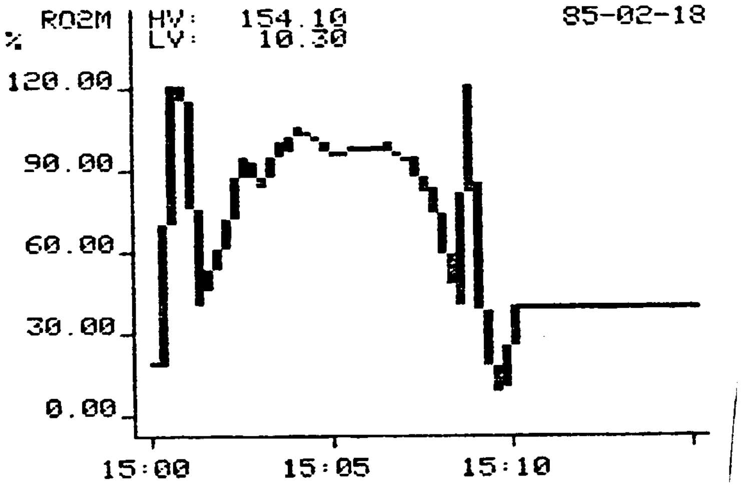


Figure 8 - Continuous history of oxygen yield (RO2M)

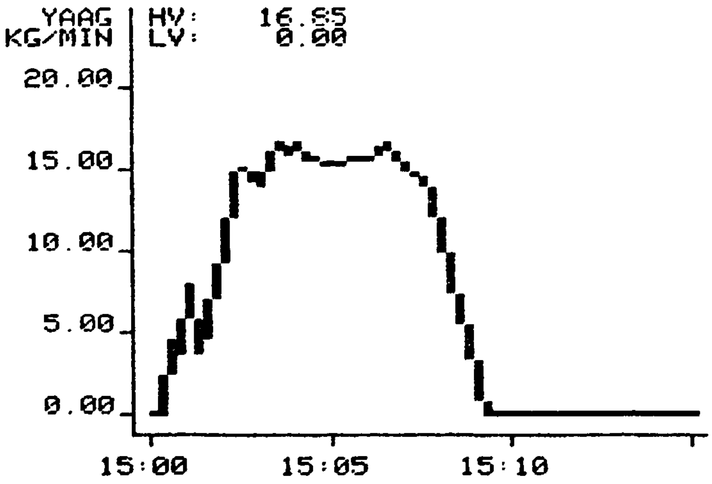


Figure 9 - Continuous history of decarburization rate (YAAG), and carbon content (A1)

3.2.4.2 MFOBM4

Functions

1 Changes in depots due to added or tapped hot metal
2 Total inputs of Si, Cr, S, Mn and P
3 Change in C-depot since last C-content update
4 Oxidized amount of Si, Cr, S, Mn and Fe
5 Metal weight
6 Special actions needed to accept a carbon content update
7 C-depot
8 Metal analysis

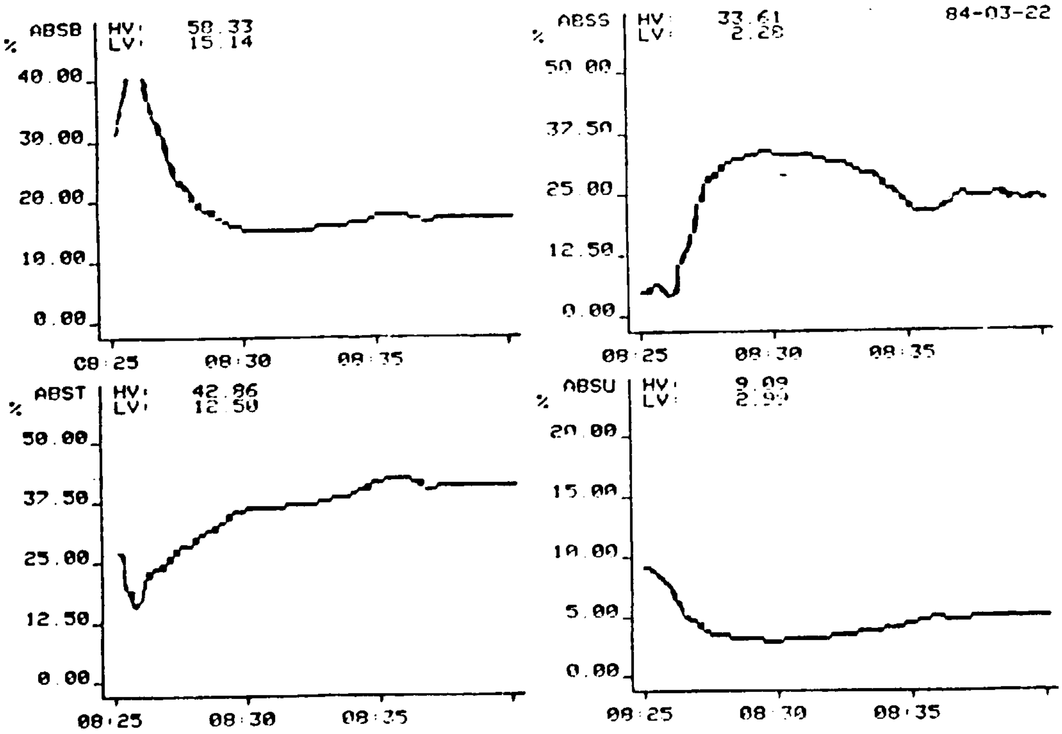


Figure 10 - Continuous history of slag analysis:
SiO_2 = ABSB, FeO = ABSS, CaO = ABST, MgO = ABSU

3.2.4.3 MFOBM5

Functions

1 Calculate physical heat in converter gas components
2 Calculate physical heat in converter gas dust
3 Calculate total heat in converter gas and dust
4 Calculate physical heat in waste gas components
5 Calculate physical heat in waste gas dust
6 Calculate total heat in waste gas and dust
7 Calculate heat input rate in steam

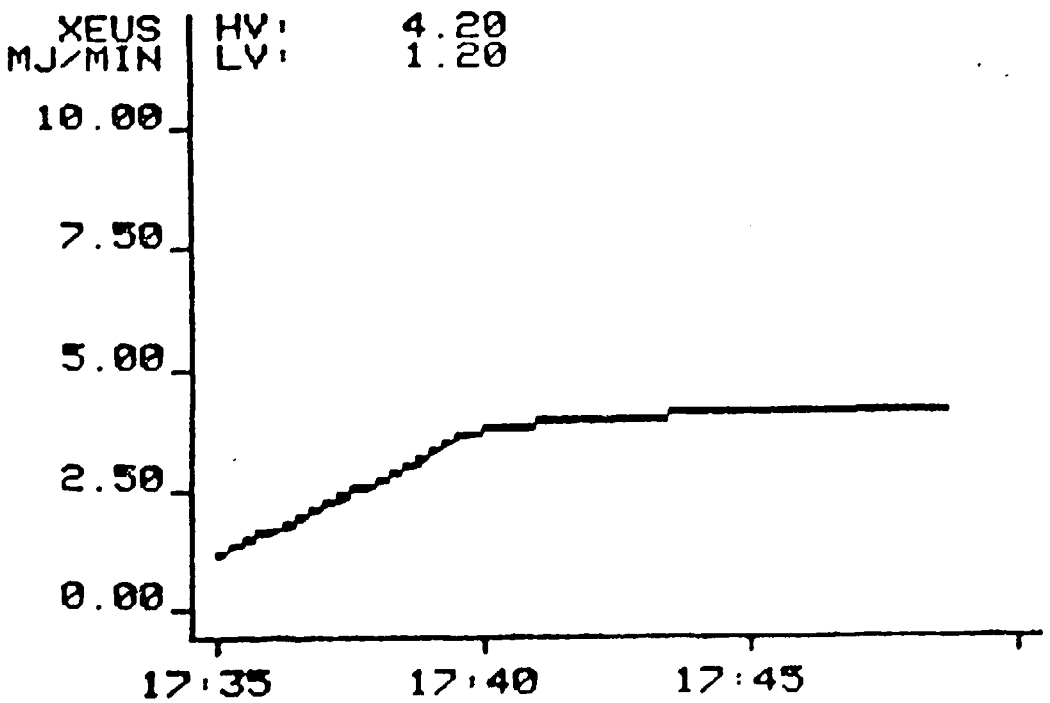


Figure 11 - Continuous history of physical heatflow (XEUS) in converter gas dust.

3.2.4.4 MFOBM6

Functions

1 Maintain status checking of digital inputs in order to detect the moment of a recently activated dispenser and on that occasion perform an update.

2 Update procedure. The purpose of update procedure is to maintain continuity in calculation of fed amounts, such as WM1, WM2, WM3 and WM4, through periods of refilling dispensers. The following actions are performed during an update.

1. Calculation of contribution to fed amount of each material from dispenser set for update.
2. Calculation of current gas weight.
3. Zero dispenser weight and write message to operator.

3 Additionally MFOBM6 sets program control flags to MFSPR.

3.2.4.5 MFOBM7

Functions

1 Function for pre-setting and holding data base table corresponding to CO/CO_2-measurements when the process is interrupted. This is to mitigate the effect of delays in the gas analysing equipment.

2 Function for correcting the measurements of H_2-analysis in converter gas and waste gas. Correction is done for the influence of $\%CO_2$.

3 Calculation of converter gas flow rate

4 Calculations of converter gas analysis if not measured. Computed elements are: CO, CO_2, H_2, H_2O, N_2, H_2S, Ar and SO_2. CH_4 must be measured or set to any selected value. Calculations of other components take the CH_4 analysis set into account

5 Calculation of certain waste gas analysis
5.1 Ar
5.2 Compensation of H_2 analysis
5.3 N_2
5.4 H_2O

3.2.4.6 MFOBM8

Functions

1 Signal processing is necessary in order to compensate values of gas flow rate for temperature and pressure, for each pipe line and media type.

1.1 Calculations for line A. Possible media types are O_2, N_2 and Ar. Default gas is O_2. All compensated AI with range given for O_2.

1.2 Calculations for line B. Possible media types are O_2, N_2 and Ar. Default gas is N_2. All compensated AI with range given for O_2.

1.3 Calculations for line D. Possible media types are C_3H_8, N_2 and Ar. Default gas is C_3H_8. AI not compensated for P&T. Compensation should be done according to the ideal gas theory.

1.4 Calculations on line E. Possible media types are N_2 and Ar. Default gas is N_2. All compensated AI.

1.5 Calculations for line F. Only possible media is steam. Orifice plate type measurement with AIs input for p, P&T. Range constant input from data base table. Compensation for actual P&T should be done according to regression against tabulated data and be valid in the complete range of interest.

1.6 Computations on line G. Only possible media type is O_2. AI input is flow rate, compensated for both temperature and pressure. Range given is valid for O_2.

1.7 Computations on line L. Possible media types are air and O_2. Orifice plate type measurement with AIs input for p, P&T. Range constant, given for O_2, should be input from data base table. Compensation for actual P&T should be done according to standard

2 For each pipe line system, check for valve combination errors and do output of alarm messages if such errors are found.

3 Do information reduction and compute oxygen yield and maximum P.

3.1 Compute the totally injected gas flow rates for O_2, N_2 and Ar.

3.2 Compute the total input of O_2 and N_2 expressed as gas flow rates.

3.3 Compute current value and average of oxygen yield

3.4 Compute maximum of P possible.

4 Compute utility control parameters for coal gasification processes only.

4.1 Compute the difference between carburization and decarburization expressed as an oxygen flow rate.

4.2 Compute oxygen set-point to obtain constant carbon depot.

4.3 Compute the quotient input O_2/set-point O_2.

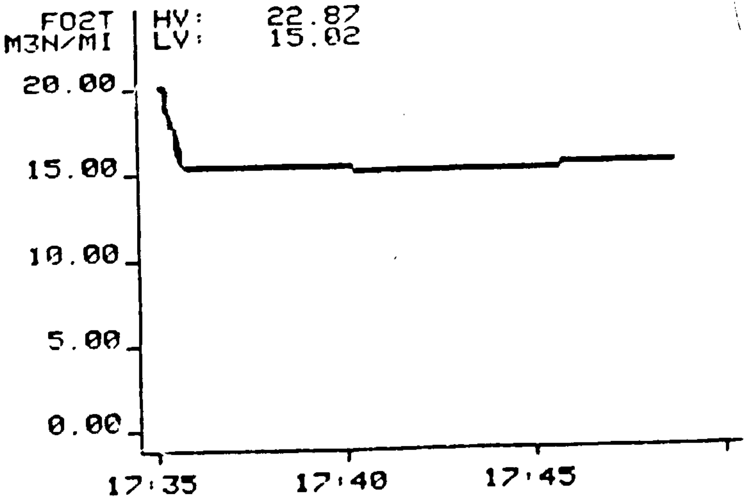


Figure 12 - Continuous history of total ingoing flow of oxygen (FO2T)

3.2.4.7 MFOBM9

Functions

1 Weight and flow rates of materials fed from bins
2 Factors for solution of lime in the slag
3 Solution and contributions from not injected materials
3.1 Dolomite
3.1.1 Solution of dolomite
3.1.2 Component contributions from dolomite
3.2 Flux
3.3 Sand
3.4 Lime-dumped
3.4.1 Solution of lime
3.4.2 Component contributions from (dumped) lime
3.5 Limestone
3.5.1 Solution of lime stone
3.5.2 Component contributions from lime stone
3.6 Iron ore
3.7 Silicon manganese
3.8 Ferro silicon
3.9 Ferro chrome
3.10 Refractory
3.10.1 Refractory wear
3.10.2 Compensated C-content in refractory
3.10.3 Component contribution from refractory
3.11 Scrap
3.11.1 Amount of scrap melted
3.11.2 Component contribution from scrap

4 Factors to be used for the distribution of oxygen oxidizing metal components

5 Gross slag weight

6 Compensations necessary for deslagging

7 Compensations necessary to slag component weights due to tapped/added slag

8 Component weights of the total slag

9 Slag basicities

10 Slag analysis

11 Unit transformation of amounts
11.1 KG O2 to M3N O2
11.2 KG H2O to M3N/MIN H2O

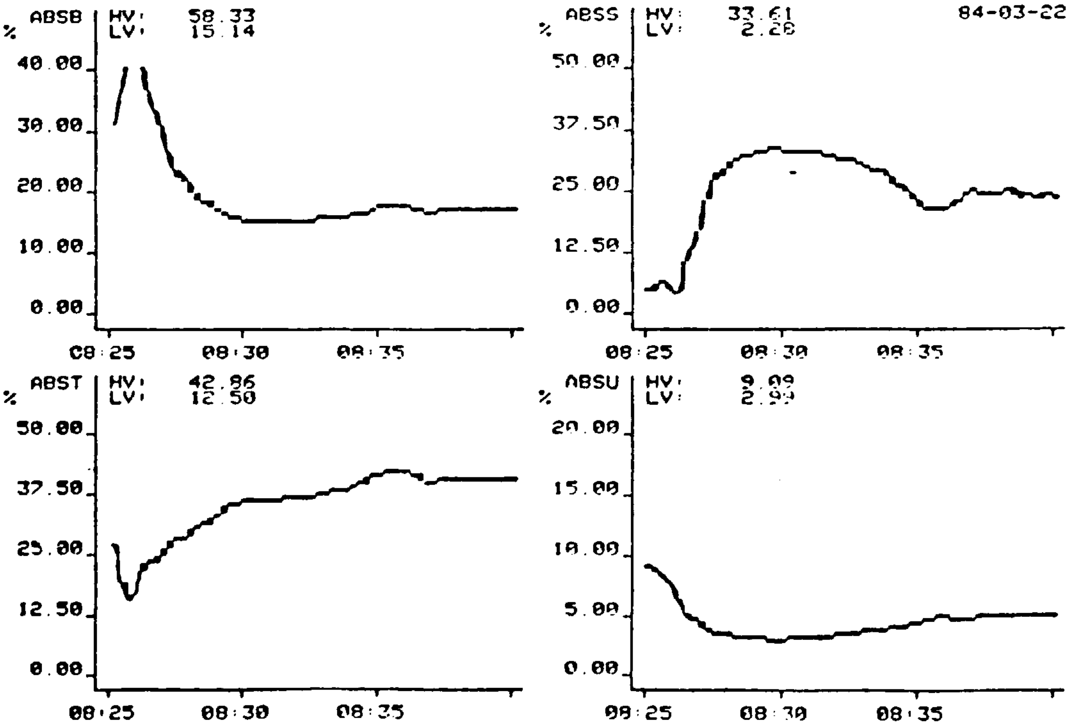

84-03-22

Figure 13 - Continuous history of slag analysis: SiO_2 (ABSB), FeO (ABSS), CaO (ABST), MgO (ABSU)

3.2.4.8 MFINTG

Functions

1 Calculate total time since initialisation

2 Maintain flag for tilted converter

3 Determinate current integration interval

4 Perform integrations
4.1 Effective blowing time (min)
4.2 Ingoing gases (m^3N)
4.3 C and S with waste gas dust (kg)
4.4 Volume of converter gas in the current integration interval ($m^3N/100$)
4.5 Converter gas components (m^3N)
4.6 Total converter gas and total waste gas
4.6.1 Dry waste gas (km^3N)
4.6.2 Wet waste gas, line 1 (km^3N)
4.6.3 Wet waste gas, line 2 (km^3N)
4.6.4 Dry converter gas (km^3N)
4.7 Enthalpy
4.7.1 Ingoing enthalpy with steam (MJ)
4.7.2 Outgoing enthalpies, gases and dust (MJ)
4.7.3 Enthalpy before waste gas boiler (MJ)
4.7.4 Total enthalpy with gases and dust leaving the converter (MJ)
4.8 Dust
4.8.1 Total slag to converter gas dust (kg)
4.8.2 Slag components to converter gas dust (kg) (SiO_2, MgO, CaO, Al_2O_3, Cr_2O_3, MnO, FeO, P_2O_5, S)
4.8.3 Total metal to converter gas dust (kg)
4.8.4 Metal components to converter gas dust (kg) (Cr, Si, Cr, Mn, Fe, P, S)
4.8.5 O_2 to converter gas dust (kg)
4.8.6 C (from metal bath) in waste gas dust (kg)

4.8.7 S (from slag and metal) in waste gas dust (kg)

4.8.8 Total amount of dust in waste gas (kg) and total amount of dust in converter gas (kg)

4.8.9 Total amount of carbon blown through the bath (kg)

4.9 Campaign integrals (m^3N)

5 Oxygen free for oxidation of metal components (kg)

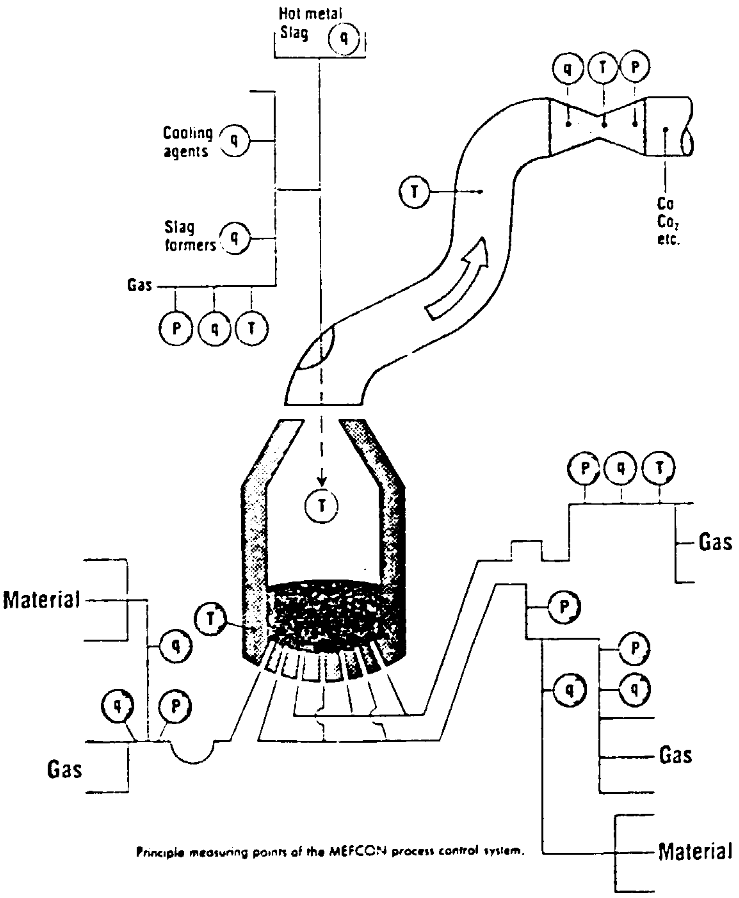

Hot metal
Slag
q
Cooling agents
q
Slag formers
q
Gas
P
q
T
q
T
P
T
Co
Co2
etc.
T
P
q
T
Gas
Material
T
q
q
P
P
P
q
q
Gas
Gas
Material
Principle measuring points of the MEFCON process control system.

Figure 14 - Principle measuring points of the MEFCON process control system

3.2.4.9 MFSPR

Functions

During rised converter and if dispenser is activated as indicated from MFOBM6, MFSPR performs calculations of

1 Gas flow rate compensation

2 Fed amount material from each dispenser since last update

3 Material flow rate

4 Amount fed material of each of four materials totally since last initialization

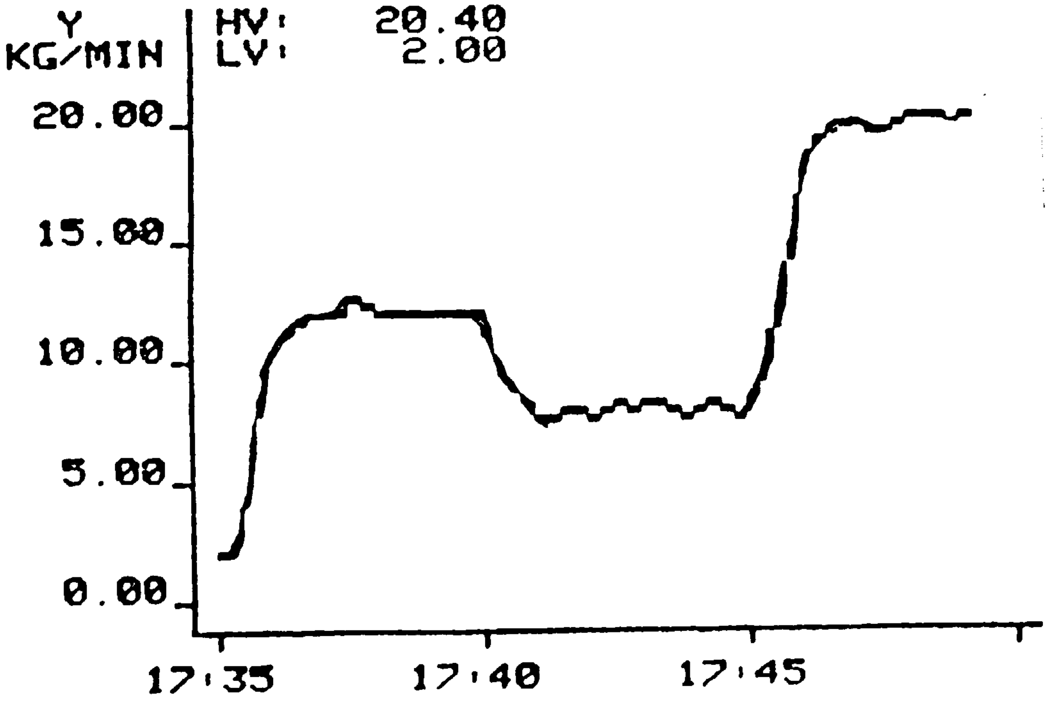


Figure 15 - Continuous history of injected material flow (Y)

3.2.4.10 MFINJM

Functions

1 Computation of Fe_3O_4 content in injected and dumped materials

2 To calculate dry material flows

3 To compute the elementary flows that correspond to the injected material flow

3.1 Flow rate of S corresponding to injected material flow

3.2 FLow rate of C corresponding to injected material flow

3.3 Flow rate of CO_2 corresponding to injected material flow

3.4 Volume flow rate of O_2 to injected material flow

3.5 Volume flow rate of N_2 to injected material flow

3.6 Volume flow rate of H_2O to injected material flow

3.7 Volume flow rate of H_2 to injected material flow

4 Calculation of weight of injected materials

5 Weights of injected component weights (S, SiO_2, MgO, Al_2O_3, CaO, H_2O, Cr, P, Mn, metall, O_2, slaggformers, CO_2 and $C+CO_2$)

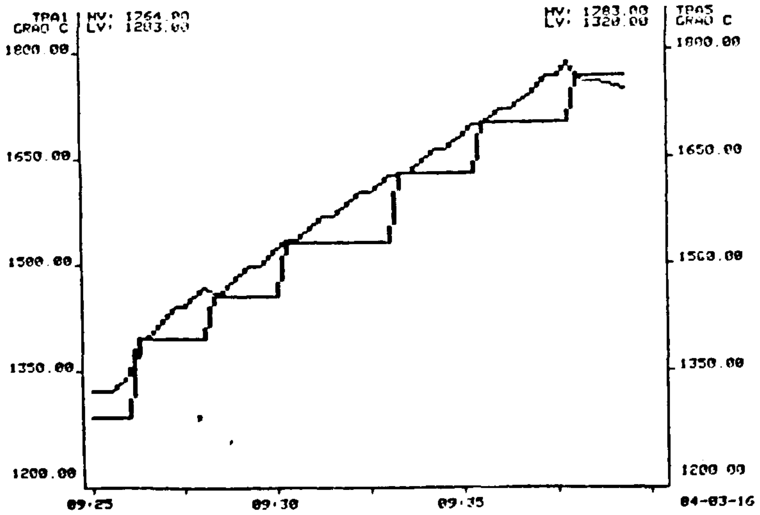


Figure 16 -

CURVES SHOWING TIME HISTORY OF SAMPLED METAL TEMPERATURE (TBA1) AND METAL TEMPERATURE CALCULATED BY MEFCON (TBA5). DATA FROM CHARGE S1366. (HARD-COPY OF OPERATOR GUIDANCE DISPLAY.)

3.2.4.11 PREBAT

Functions

1 The module is responsible for calculating the current temperature of the melt based on a heat balance for the converter

1.1 Actions needed to handle initialization for a new charge with respect to the temperature calculation

1.2 Actions needed to adapt to a sampled temperature. Calculation of accumulated heat in the converter at the time when the temperature was measured

1.3 Change in the accumulated heat since the last temperature measurement. The calculation should be based on the following

- Calcination of four types of limes, dumped and injected
- Reduction of iron concentrate, dumped and injected
- Reduction of dumped gabbro
- Oxidation of Fe, Mn, Si, P and Cr to slag
- Cracking of propane
- Formation of CO in converter gas
- Formation of CO_2 in converter gas
- Formation of CH_4 in converter gas
- Formation of H_2S in converter gas
- Physical heat in the converter gas
- Heat of solution for C, Si, P and Cr
- Compensation when the carbon content is updated

1.4 Temperature calculation, based on weight of the melt and current accumulated heat in the converter

2 Prediction of bath temperature using extrapolation of measured temperatures up to current time

3.2.4.12 MFDUST

Functions

To calculate the flow rate of dust from metal bath and slag and subdivide this flow rate into flow rates of certain elements. The dust flow rate should be calculated either as a polynomical regression against bath temperature or as a factor (possibly computed) multiplied by converter gas flow. The flow of C blown through the metal bath should also be calculated.

1 Carbon blown through bath
2 Losses of metal to dust
2.1 Losses of metal components to dust (C, Si, Cr, Mn, Fe, P and S)
3 Losses of slag to dust
3.1 Losses of slag components to dust (SiO_2, Cr_2O_3, MnO, FeO, P_2O_5, S, CaO, Al_2O_3 and MgO)
4 Flow of metal and metal components in converter gas dust
5 Oxygen to dust in converter
6 Converter gas dust analysis, metal phase
7 Flow rate of slag and slag components in converter gas dust
8 Converter gas dust analysis, slag phase
9 Flow rate of metal and metal components in waste gas dust
10 Oxygen to dust in waste gas
11 Waste gas dust analysis, metal phase
12 Total carbon that is not combusted in converter gas and waste gas
13 Flow rate of slag and slag components in waste gas
14 Waste gas dust analysis, slag phase

3.2.4.13 MFCTRL

Functions

1 Start-up initialisation

1.1 Compute own periodicity, preset common flags, values in data-base tables, and time counters

1.2 Read back-up copy of GLOBAL area from disc

2 Maintain counters for timing and when time conditions are fullfilled, start corresponding link of programs within the MEFCON-package

3 Every five minutes, put a time stamp with the current time on the GLOBAL area, then store the GLOBAL area on disc for cold start and back-up purposes.

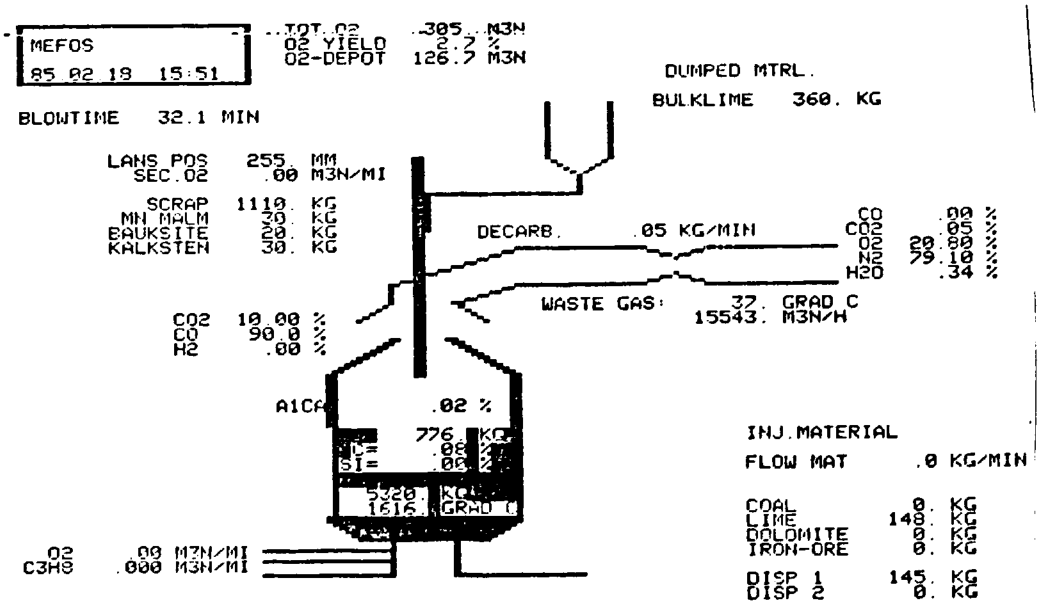

MEFOS
85 02 18 15:51
TOT.O2 .305 M3N
O2 YIELD 2.7 %
O2-DEPOT 126.7 M3N
BLOWTIME 32.1 MIN
DUMPED MTRL.
BULKLIME 360. KG
LANS POS 255. MM
SEC.O2 .00 M3N/MI
SCRAP 1110. KG
MN MALM 30. KG
BAUKSITE 20. KG
KALKSTEN 30. KG
DECARB. .05 KG/MIN
CO .00 %
CO2 .05 %
O2 20.80 %
N2 79.10 %
H2O .34 %
WASTE GAS: 37. GRAD C
15543. M3N/H
CO2 10.00 %
CO 90.0 %
H2 .00 %
A1CA .02 %
776. KG
C= .08 %
SI= .00 %
5320. KG
1616. GRAD C
O2 .00 M3N/MI
C3H8 .000 M3N/MI
INJ.MATERIAL
FLOW MAT .0 KG/MIN
COAL 0. KG
LIME 148. KG
DOLOMITE 0. KG
IRON-ORE 0. KG
DISP 1 145. KG
DISP 2 0. KG

Figure 17 - Dynamically updated picture with current values of process parameters such as carbon analysis, temperature, slag weight, oxygen yield, decarburization rate ....

3.2.4.14 MFOBMI

Functions

1 Initialisation for new charge
2 New charge number is set and period number is set to zero
3 Initialisation of stack for referens samples
4 Initialisation of logic-parameters
5 Initialisation of dispensers and bins
6 Charge data is transfered to calculated values (metal-analysis, slag-analysis, metal-weight, slag-weight, metal temperature)
7 Component quantities from added/tapped metal is calculated
8 Depots due to C-updating is sel to zero
9 Slag component quantites set to zero
10 Ingoing material quantites set to zero
11 Integrals of ingoing gases set to zero
12 Integrals of outgoing gases and dust set to zero
13 Turn off signal for feeding from bins
14 Total and effective time set to zero

3.2.4.15 MFINTR

Functions to be performed

MFAF

1 To maintain a measure of operation status for all signals from gas analysers according to the status of the associated digital inputs and to initiate a notification about analyser status changes to the process operator.

MFINIT

2 To define a new heat and mass balance time interval to the module responsible for print out of this report and to initiate a report print out.

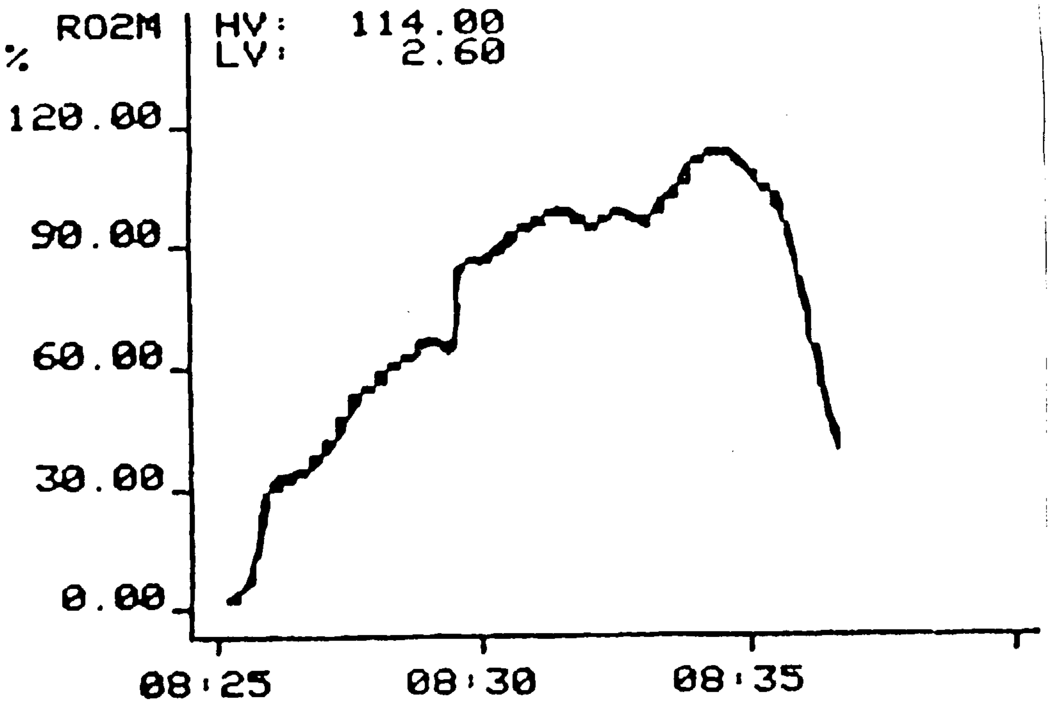


Figure 18 - Continuous calculated oxygen yield (RO2M)

3.2.4.16 UPKOLH

Functions

This module should include functions necessary to adapt the MEFCON s/w to results given by sampling the carbon content of the metal bath. The adaption should be done by writing the correct current status of metal analysis, change in oxygen depot, oxygen distribution factors and slag analysis and weight, that corresponds to any given sample result, to the data base tables. Also logical flags, intended for the temperature estimating module and the execution control module, should be maintained.

The following events should be foreseen

- A sample is taken. The module will be started.
- A sample result is given. The module will be started.
- A "message" that the last sample taken is invalid. The module will be started.

This module should recognize the three cases above by inspection of a flag-word in the SYS-table.

Up to twenty samples could be taken before any result is returned. Sample results and new samples taken could then follow in any order, provided however, that no more than twenty samples are not answered at any specific point in time.

Functional breakdown

1 Sample is taken
1.1 Flag to execution control module
1.2 Maintain stacks for sample taken case
1.3 Special action of first sample. The error resulting from the 1st sample in any charge should be considered to be due to incorrectness in the given start analysis. Following errors should be considered to depend on measurement errors in the waste gas system
1.4 Store necessary values for later update of current status
1.5 Notify operator

2 Sample result is returned
2.1 Maintain stacks for sample result case
2.2 Correct O_2 and C-depots as to be able to handle yet unanswered samples
2.3 Get stored values and pop stack
2.4 Get the analysis result and check for validity before acceptance
2.5 Recalculate oxygen distribution on elements in slag
2.6 Compute the corrected O_2 of C-depots that corresponds to the analysis result given by the sample

3 Adapt the changes found of the O_2 and C-depots to real time calculations at current time
3.1 Get current data and correct values for O_2 and C-depots
3.2 Compute slag analysis and oxygen distribution factors
3.3 Compute new slag and metal analysis according to best data available

3.4 Compute new distribution of oxygen on slag components according to best data available
3.5 Recalculate total amount oxidized metal
3.6 Current C-content, the sample result considered
3.7 Effectuate update by writing values to database
3.8 Set flags to notify other MEFCON modules
3.9 Notify operator and maintain corrections to O_2 and C-depots due to stacked samples

4 Cancellation of the last sample taken
4.1 Set flags to notify other modules about cancellation
4.2 Maintain stacks and pointers for cancellation
4.3 Notify operator

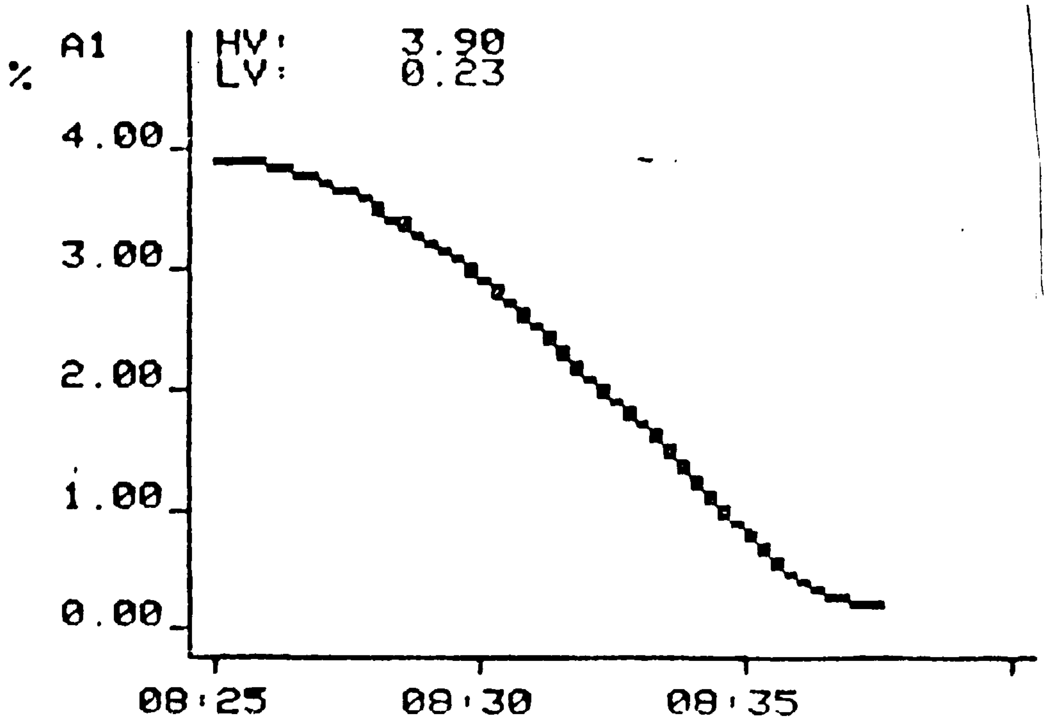


Figure 19 - Continuous calculated carboncontent in the bath (A1)

3.2.5 PROCESS EQUIPMENT

Process equipments considered by the MEFCON s/w includes the following

Reactor system
Material handling system
Waste gas system
Process media system
Sampling system

3.2.5.1 Reactor system

The s/w is prepared to handle a reactor which has facilities for bottom blowing and for top blowing, either with or without material injection, in any combination. Besides these primary systems, oxygen or air is allowed for post combustion. Furthermore the reactor construction may or may not allow for continous analysis of the convertergas. Not to be regarded as necessities, these measurements will, in case of presence be handled by the s/w and, further, slightly improve the accuracy of the calculations.

3.2.5.2 Material handling equipment

The material handling equipment foreseen could be divided into systems for
material injection
material adding
charging/tapping

Material_injection_equipment

The original s/w have functions to handle 3 independent dispensers. Any dispenser might contain any mixture of up to four different materials, one of them beeing coal. Two different inert carrier gases are handled, possibly automatically switched. Besides, oxygen is considered to be a possible carrier gas (injection of lime powder).

The construction of any dispenser is assumed to be such that it is possible to measure its weight and the pressure of the enclosed gas. Also, digital indication is needed for filling and off-line conditions.

Material_adding equipment

The original s/w includes handling of three bins for material adding.
Each bin is considered to contain a homogeneous mixture of different materials. Also, MEFCON s/w allows any material in a bin to be exchanged for another material without any action required other than a simple operator command.
The construction of a bin is assumed to be such that it is possible to measure the weight of the bin. Furthermore the filling of a bin is assumed to be done batchwise.
If a bin is equipped with feeding machinery of any kind, and a digital indication exist telling the current operating condition of this machinery, the MEFCON s/w outputs a digital signal that can be used to do on/off control of this feeding machinery with the aim to achive a predetermined fed amount in a certain period of time.

Charging/tapping_equipment

Charging & tapping equipment is assumed simply to consist of a crane and ladles. The crane is assumed to have a balance with the possibility to mark and send (or hold) the measured weights to the computer. If not, these weights must be submitted to the software in another (low forseen) way.

3.2.5.3 Waste gas system equipment

The MEFCON s/w will work if the waste gas equipment is an open, unpressurized system for combusted gas, with or without any air inled at the top of the reactor, as well as if it is a closed, possibly pressurized, system for uncombusted gas. Thus, situations when start conditions imply an open system with combusted gas, and operating conditions a closed system with not combusted gas, with an intermediate switchover, will be fully handled by MEFCON. Also, the waste gas cleaning equipment may be divided into two parallel lines without imposing changes to the code.

However, some considerations concerning the construction of the waste gas system are of ultimate importance for the reliability of MEFCON. This is so because the software heavily relies on the assumption that inputs to, as well as outputs from the reactor are possible to measure and to identify. This explicitly means that it should be possible to measure the process gas flow rate, or parts of it needed to form a sum of several cleaning lines, possibly including air inlets (or gas outlets), but not including any other additions, in so far as these are not precisely defined with respect to both amount and composition. This restriction is caused by the need to combine the measured flow rate with the correlated gas composition in order to do on line computations necessary for the mass balance of the process. Thus, in practice, flow rate measurement should exist and furthermore it ought to be located between the reactor and such equipment as a venturi scrubber. If not, it is considered to be a user responsibility to adapt the value of the waste gas flow rate available to the result expected by MEFCON, due to the software design.

Obviously, of ultimate importance, is the possibility to "continuously" measure the gas composition correlated to the value of the flow rate available with respect to all main components, including elements of coal or oxygen, but possibly excluding H_2O if the restrictions above are met. In fact, the restrictions under the circumstances mentioned are partly imposed by the practical difficulties to get sufficient, reliable and complete measurements of the gas composition in line with difficulties also to compute missing parts of the composition due to lack of data.
The assumptions made in the original code are that there is a waste gas flow rate measurement in the dry parts of the waste gas system, that the measurement equipment is a venturi tube calibrated with cold gas, and that there is a possibility to clean (blow) the impulse tubes of this venturi tube during operation.

3.2.5.4 Process media system

All gases and fuels put into the reactor are assumed to be measured. In case different types of gases are switched into a certain pipe line, it is also necessary to indicate to the computer which gas is currently present in that pipe. This possibility also brings with it the requirement to place the primary measurement equipment in different pipes in such a way that no measurement ever will be done on a gas mixture, i.e. only one gas type at a time should be permitted for each measurement. Besides these considerations, any configuration of the media system could in principle be handled by the software, the step required for any installation being to reconfigure the software solution in the module MFOBM8.

3.2.5.5 Sampling system

Equipment for sampling the bath temperature and equipment for sampling the bath analysis are supposed to supplement any installation.

The sampling of the bath analysis could, as far as the s/w is concerned, be carried out using any equipment because the s/w is delivered with the inherent claim that the operator should notify the s/w when sampling is done (for example by pushing a button) and when the sample result is returned. The system then will ask the operator to input the sample result. This procedure should be exchanged and adapted to the actual sampling equipment in any installation in a way that all the conversation takes place between the computer and the sampling equipment, making operator interaction unnecessary.

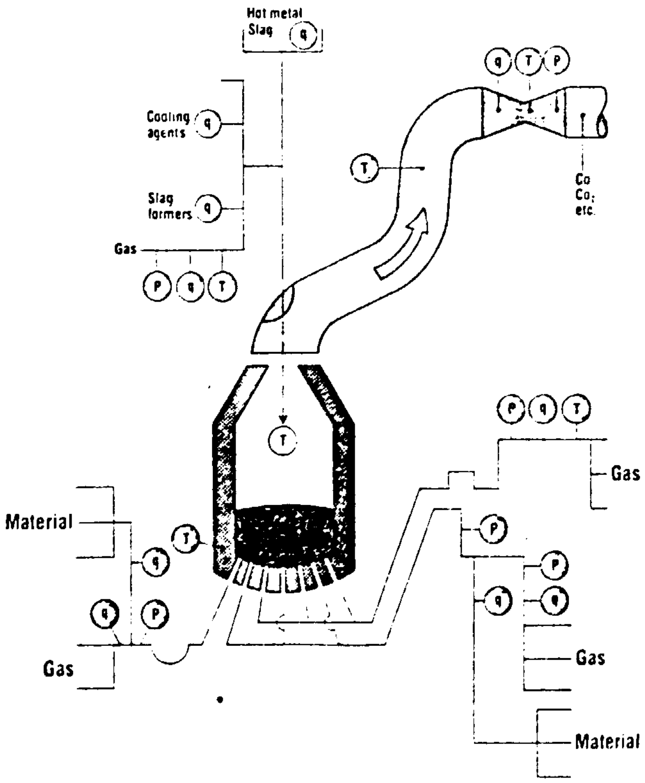

Hot metal
Slag
q
q
T
P
Cooling agents
q
T
Co
Co₂
etc.
Slag formers
q
Gas
P
q
T
T
P
q
T
Gas
Material
T
q
P
q
P
P
q
q
Gas
Gas
Material

Figure 20 - Principle measuring points of the MEFCON process control system.

3.2.6 INSTRUMENTATION

In the following the different measurements and other signals used are discussed according to the following grouping.

A Time reference
B Sampled values
C Waste gas system
D Surroundings
E Process gases and other utilities
F Material injection systems
G Materials dumped and added
H Charging/tapping

3.2.6.1 Time reference

Different numerical approaches, like integrating and filtering, cause the need of an accurate time measure between different s/w events. These time measures are supposed to be obtainable from the computer system itself by different operating system calls although the absolute time of the day might be given or triggered by any external clock.

Time parameters are utilized by the modules MFCTRL, MFINTG, PREBAT, MFSOND, MFOBM6-7 and MFVIKT.

3.2.6.2 Sampled values

All measurement signals except two are supposed to be of continous nature, i.e. either true analogue signals or formed by fast scanning with held output.
The two sampled values that are handled by the MEFCON s/w are the bath temperature, when measured with a sonde, and the analysis (carbon content) of the metal bath, sampled anytime.

Also, the sampled result of the hot metal analysis, the analysis of the start slag if any, and the temperature of the hot metal, should be input to the corresponding data base tables before start of blowing and charge initialization.

If and when the bath temperature is sampled, the s/w does an evaluation of the thermocouple signal and adapts the computation of heat losses in a way that the calculated temperature equals the measured result at the point of the sample. This is true for all samples except the first one.

If and when the carbon content of the bath is sampled while blowing, the following sequence of actions will be performed by the s/w. First, at the point in time the sampling actually is done, the s/w stores a number of parameters together with an index, all valid at this specific point in time. Any time later when the sample result is returned (given in the unit "percentage of carbon"), stored data from the sampling point for this particular sample are, together with current data and the result given, used to calculate corresponding changes in the current status. Finally, an update of the current status is done to reflect the sample result. This technique allows different sample results to be input in any order and at any time after the actual sampling.

Sampled analyses are utilized in the modules MFOBM4, MFOBM9 and UPKOLH. Sampled bath temperature is evaluated by MFSOND and then used by PREBAT. MFSOND assumes that the equipment for sampling provides with 1-5 digital inputs to identify the measurement station, and 1 digital input to identify a slag temperature measurement. Also one digital output, to notify the operator that a measurement is in progress, and one analoque output, holding the evaluated value of the bath temperature, are maintained by the s/w.

3.2.6.3 Waste gas system

Potentially possible measurements in the waste gas system, that are of actual interest for the calculation of process status parameters, are the flow rate of dry waste gas, the waste gas composition and pressure, and the waste gas temperature measured as close to the reactor as possible. However, commercially available equipment to measure dry flow rate, to continously measure %H_2O in the waste gas, or equipment to continously analyse the wet waste gas is hard to find. This is why another approach is used in the MEFCON s/w, meaning that what the s/w assumes to be measured is, indirectly the wet waste gas flow rate by actually measuring a differential pressure, pressure and temperature, the dry gas analysis of all main gas components excluding %H_2O which is computed, and a separate gas temperature as close to the reactor as practical.

A special function is included in the s/w to handle a situation when the impulse tubes, connected to the differential pressure measurement, is blowed/cleaned. This function is activated by a digital input.
Another function is included to handle a situation when one (or more) of the gas analysers are put out of operation. This function is also activated by different digital inputs, one for each analyser.

If the MEFCON s/w is expected to operate with extreme accuracy, special consideration should be given to the gas analysers which are analysing the main carbon and oxygen elements of the waste gas. Also some attention should be paid to the gas system affined to the analysers. Complete, well documented and precise calibration data for the flow rate measurement equipment will also help.

The digital inputs originating from the gas analysers are handled by the module MFINTR and the measurements in the waste gas system primarily used by the modules MFOBM1 and MFOBM7.

3.2.6.4 Surroundings

Because the approach is that no measurement is available of the %H_2O in the waste gas, the absolute value of the air humidity (gH_2O/kg air) is needed in the calculations. Thus the relative air humidity, the air pressure and the air temperature are assumed to be measured in the vicinity of the reactor. Also, the air pressure is needed in the calculation of the (wet) waste gas flow rate.
Data from the surroundings are used by the module MFOBM1.

3.2.6.5 Process gases and other utilities

Three different types of measurements are handled:
For one type of measurement equipment, the actual compensated (for pressure and temperature) flow rate is input to the computer (see line A, B, E and G in appendix 4). The MEFCON s/w then only compensates for the normalized density of the gas type (N_2/O_2/Ar). For this purpose two digital inputs are used, one telling if the current gas is O_2 or not, and the other if the gas is N_2 or Ar.

The second type of measurement equipment is an example of the treatment for a flow rate measurement, based on the relation between the frequency of oscillations induced by turbulence to a bar inserted in a fluid media, and the velocity of the media. For this type the uncompensated flow rate, the temperature and the pressure are input to the computer. The s/w then compensates the flow rate according to the ideal gas approximation.

The third type of measurement equipment represents any orifice plate measurement and similair measurements. The differential pressure, temperature and pressure are all input to the computer. The calculations of the flow rates then are done according to Bernouilles theorem. A special case of this type is an orifice plate measurement on steam flow, especially because of the "non-ideal" behaviour of this gas.

The MEFCON s/w also includes treatment of parallel, alternative and switchable measurement lines, one equipped for a small range (i.e. small orifice plate) and the other with a wider range. The s/w determines which range is currently in operation by testing a separate digital input for each parallel line arrangement.
Measurement on process gases are primarily handled by the module MFOBM8.

3.3.6.6 Material injection systems

The material injection systems include dispensers and the piping connected to these. The MEFCON s/w handles three dispensers of which the first one is allowed to use oxygen as a carrier gas. Besides, all three dispensers are handled for nitrogen and argon as a carrier gases. The s/w assumes that the filling of any dispenser is a batch process, indicated by a separate digital input for each dispenser. Furthermore, each dispenser should be placed on load-cells giving a weight signal to the computer. Measurements of the gas pressure inside each dispenser and the carrier gas flow rate(s) before dispensers are also foreseen. Furthermore, if the dispensers allow the enclosed gas to be exhausted to the surrounding air, a separate digital input for each dispenser should indicate this situation accordingly. For logging and supervision purposes only, it is also recommended to measure the pressure in the material injection pipe.

If accuracy of the calculations is of interest, some attention should be paid to the choice of load cells and load cell instrumentation, as well as the mechanical arrangement, considering hysterises, linearity, thermal stability and calibration accuracy. These signals also put demands on the computer A/D-conversion. It is recommended that the A/D-conversion be performed with at least 13 bits, and also well calibrated and stable enough to give significance to the last bit (in case of 13 bits).

In case of a pressure measurement in the carrier gas pipe in front of any dispenser, it should be verified that this signal has no resonance peaks in the ultra sound frequency range. If so, this might be fatal for the operation of the computer H/W.
Signals originating from the material injection system are primary handled by the modules MFOBM6, MFSPR and MFOBM8.

3.2.6.7 Material dumped and added

Materials dumped or added otherwise are assumed to come from any of three batch filled bins, or possibly directly from a crane weigher arrangement. In case of materials added by use of a crane, either an s/w module must be added that determinates the type of material (see 6.8 below), or the same function must be perfomed by the process operator by use of the operator communication s/w facilities together with the output available from the module MFVIKT. For the s/w to handle the bins correctly, a very well damped load cell signal for each bin must be available together with one digital input telling "power to feeding machinery off", and one digital input telling that the "bin output is closed". A s/w function for ON/OFF-control of each bins feeding machinery is also provided. This makes it possible to automatically add a certain amount of any material per minute without operator intervention. For this purpose, one digital output for each bin is used.

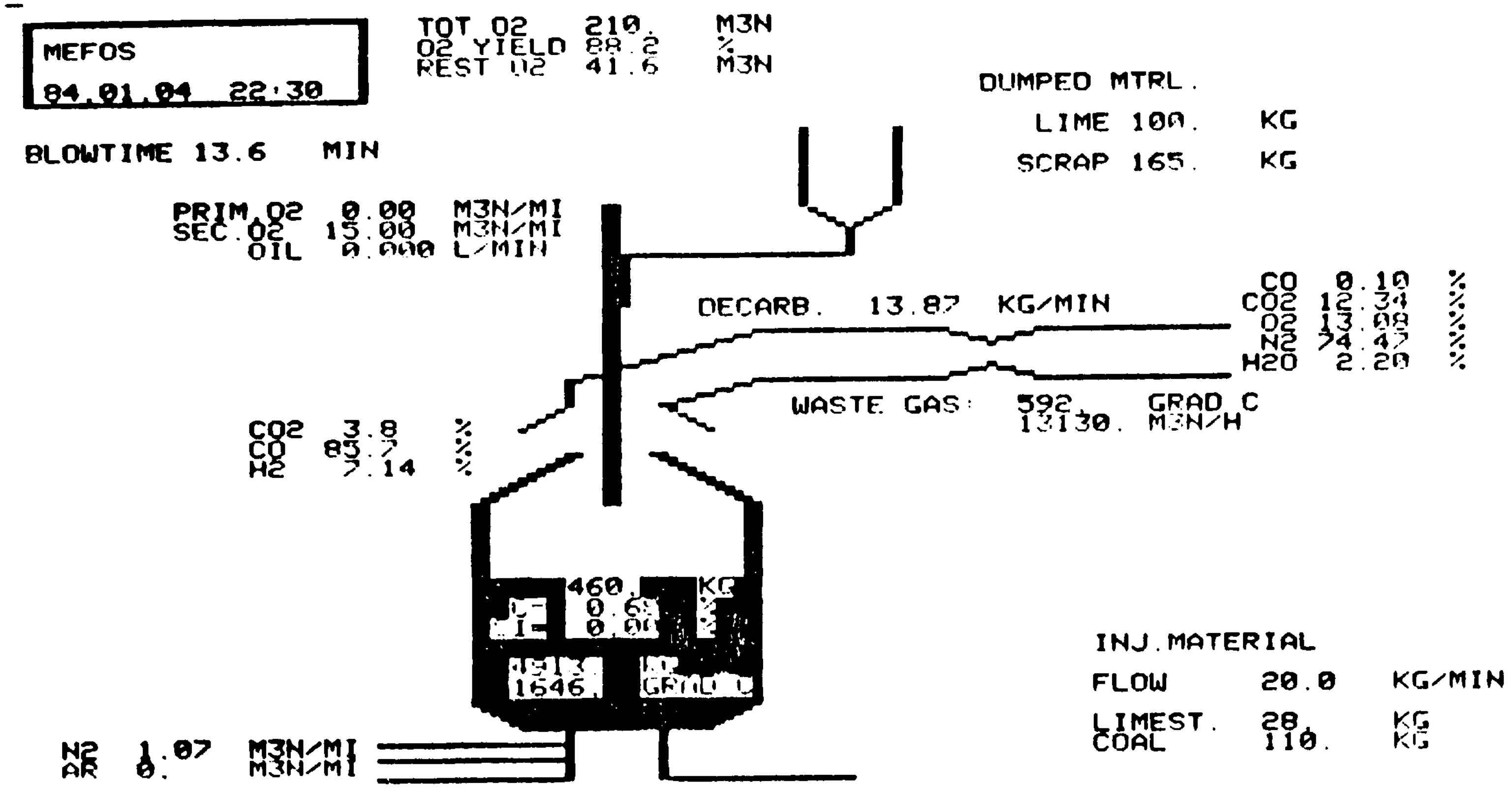
Signals from bins are handled by the module MFOBM9. Signals from the crane weigher are handled by MFVIKT.

3.2.6.8 Charging/tapping

Charging/tapping conditions are recognized by the s/w by a limit switch controlled by the reactor position and connected to a digital input.
The weight of the charged/tapped hot metal/slag is assumed to be present as an analogue signal from a crane weigher, and will in this case be handled by the module MFVIKT. However, this module does not transport the evaluated weights to the appropriate data base tables, but leaves the results in a kind of "note-book". Therefore it is considered a responsibility of the process operator to look in this "note-book" and then key the value found to the data base table that corresponds to this weight. Of course this function could also be achieved by adding a small s/w routine to the MEFCON s/w.

Besides the analogue signal, MFVIKT also assumes 6 digital inputs to be available from the crane equipment and operated by the crane operator. Two of these digital inputs are used to indicate start of weighing and whether the ladle is full or empty. The remaining four inputs indicate the contents in the ladle such as input metal, output metal and slag type.

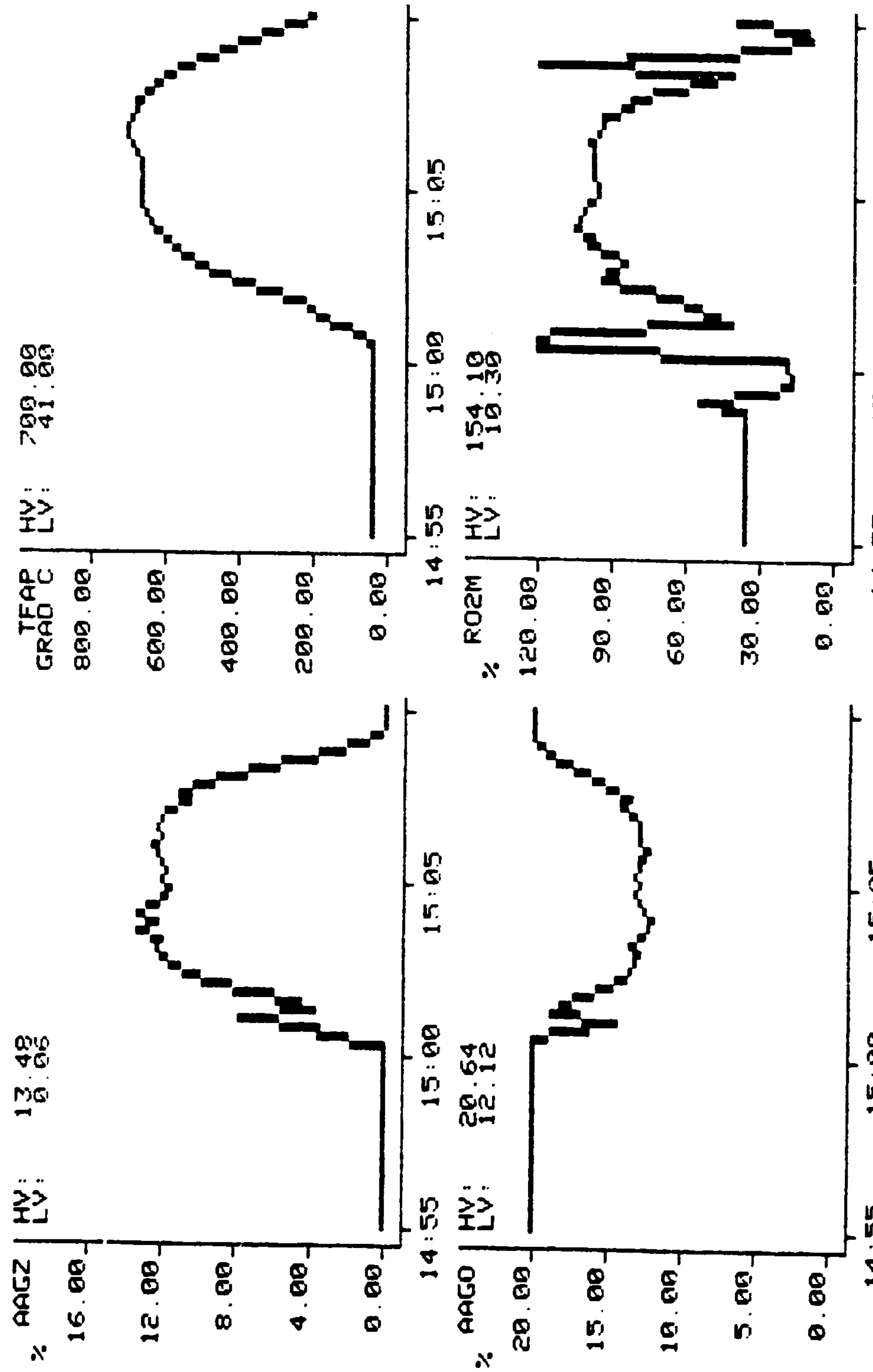
DYNAMICALLY UPDATED PICTURE WITH CURRENT VALUES OF PROCESS PARAMETERS SUCH AS CARBON AND SILICON ANALYSIS. TEMPERATURE. SLAG WEIGHT. OXYGEN YIELD. DECARBURIZATION RATE......



```
MEFOS
84.01.04  22:30

BLOWTIME 13.6   MIN

TOT O2     210.   M3N
O2 YIELD   88.2   %
REST O2    41.6   M3N

PRIM O2    0.00   M3N/MI
SEC O2    15.00   M3N/MI
OIL       0.000   L/MIN

DUMPED MTRL.
  LIME 100.    KG
  SCRAP 165.   KG

DECARB.   13.87   KG/MIN

CO    0.10   %
CO2  12.34   %
O2   13.08   %
N2   74.47   %
H2O   2.20   %

WASTE GAS:   592.   GRAD C
           13130.   M3N/H

CO2   3.8    %
CO   85.7    %
H2    7.14   %

460   KG
0.6   %
0.00  %
1646  GRAD C

INJ.MATERIAL
FLOW      20.0   KG/MIN
LIMEST.   28.    KG
COAL      110.   KG

N2   1.07   M3N/MI
AR   0.     M3N/MI
```

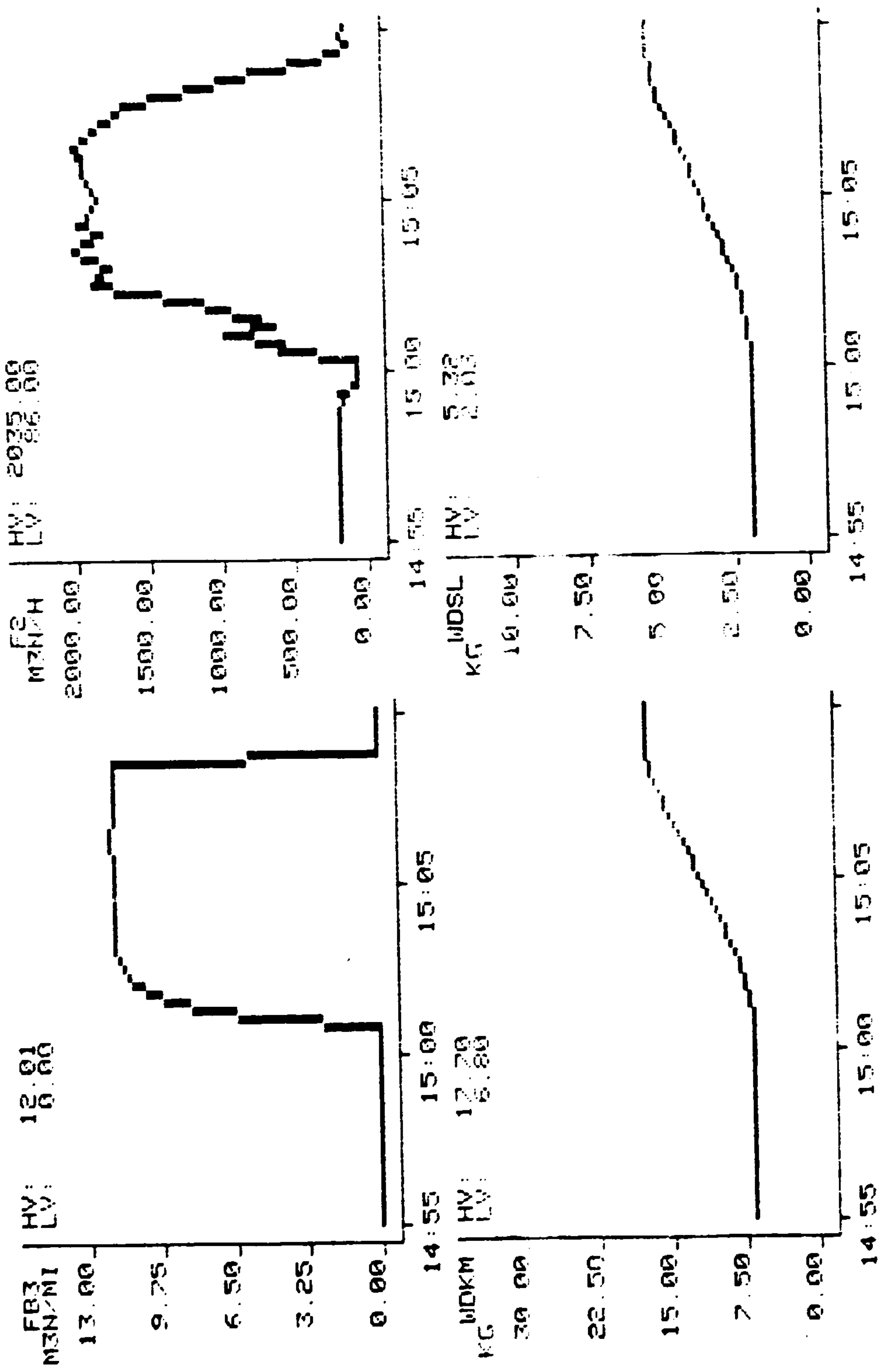
APPENDIX 2

CONTINUOUS HISTORY OF WASTE GAS ANALYSIS: CO_2(AAGZ). O_2(AAGO). WASTE GAS TEMPERATURE BEFORE COOLER (TFAP) AND OXYGEN YIELD (RO2M) ......



NOTE. CHARGE S-1400 AT MEFOS. CURVES ARE HARD-COPIES OF ONE OPERATOR GUIDANCE DISPLAY WHICH IS UPDATED ON-LINE AT 15 SEC INTERVALS.

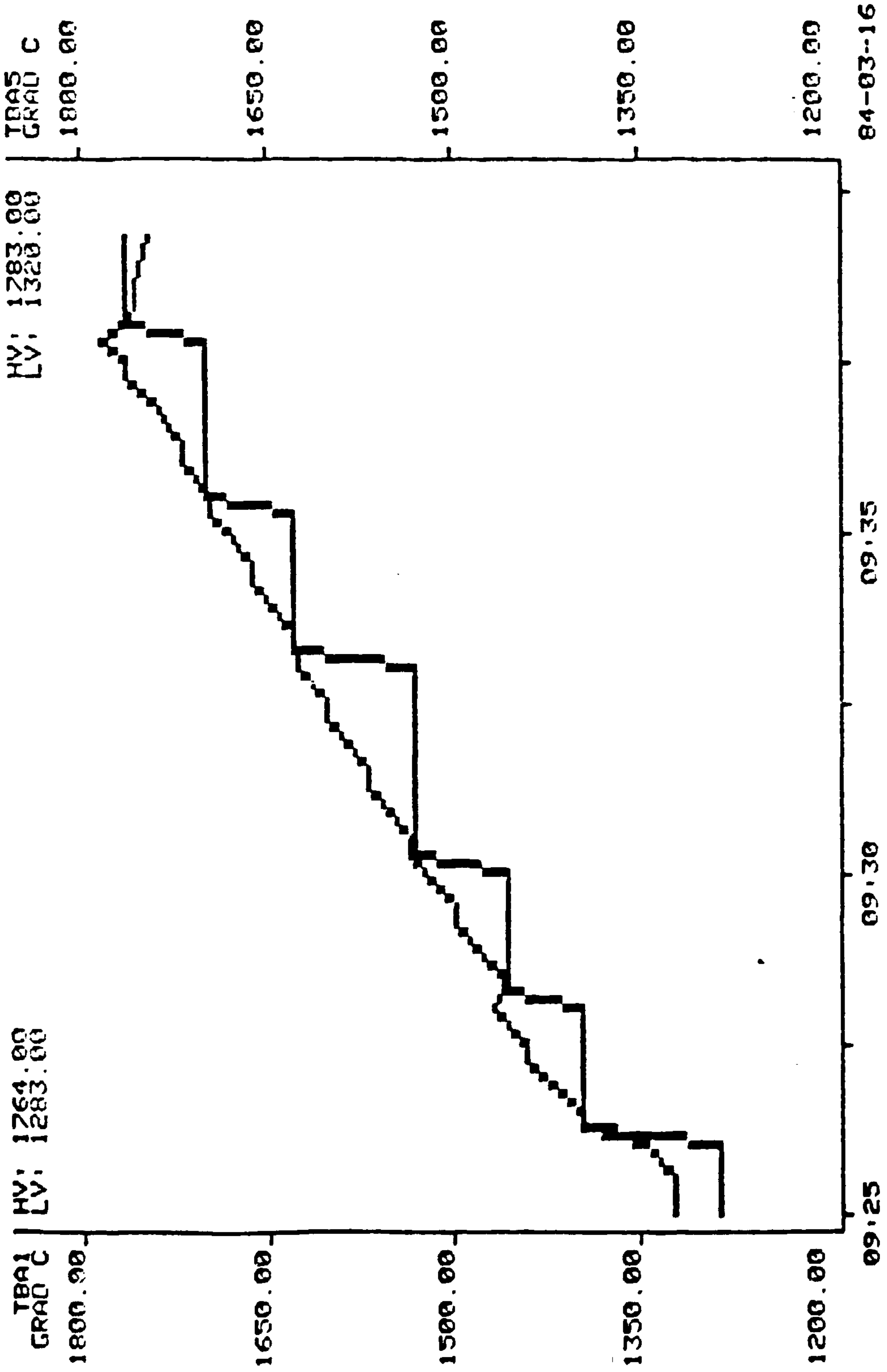
CONTINUOUS HISTORY OF OXYGEN FLOW RATE (FB3). CONVERTER GAS FLOW RATE (F2) AND DUST LOSSES FROM METAL (WDKM) AND SLAG (WDSL). . . . . .



NOTE. CHARGE S-1400 AT MEFOS. CURVES ARE HARD-COPIES OF ONE OPERATOR GUIDANCE DISPLAY WHICH IS UPDATED ON-LINE AT 15 SEC INTERVALS.

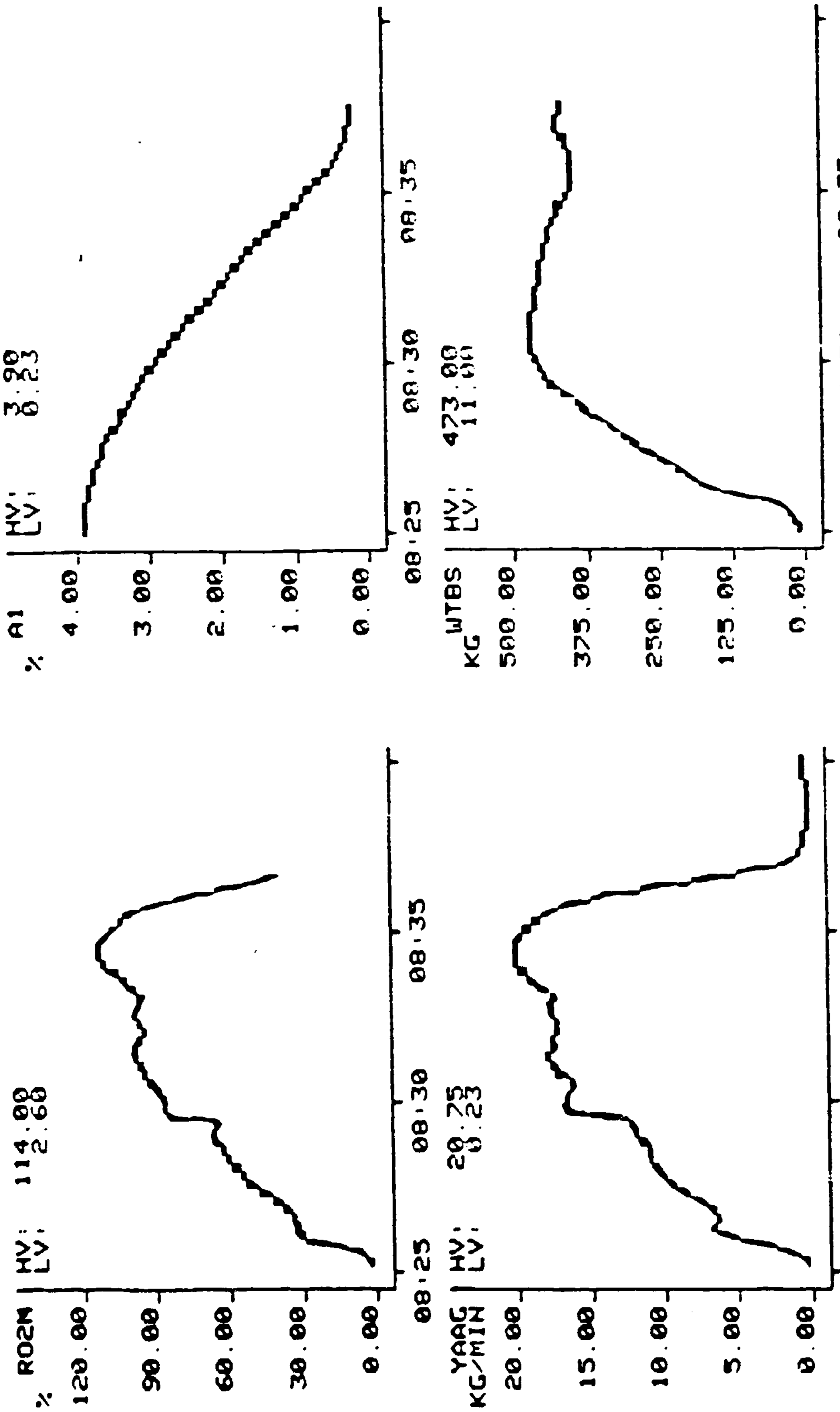
APPENDIX 4

CURVES SHOWING TIME HISTORY OF SAMPLED METAL TEMPERATURE (TBA1) AND METAL TEMPERATURE CALCULATED BY MEFCON (TBA5). DATA FROM CHARGE S1366. (HARD-COPY OF OPERATOR GUIDANCE DISPLAY.)



APPENDIX 5

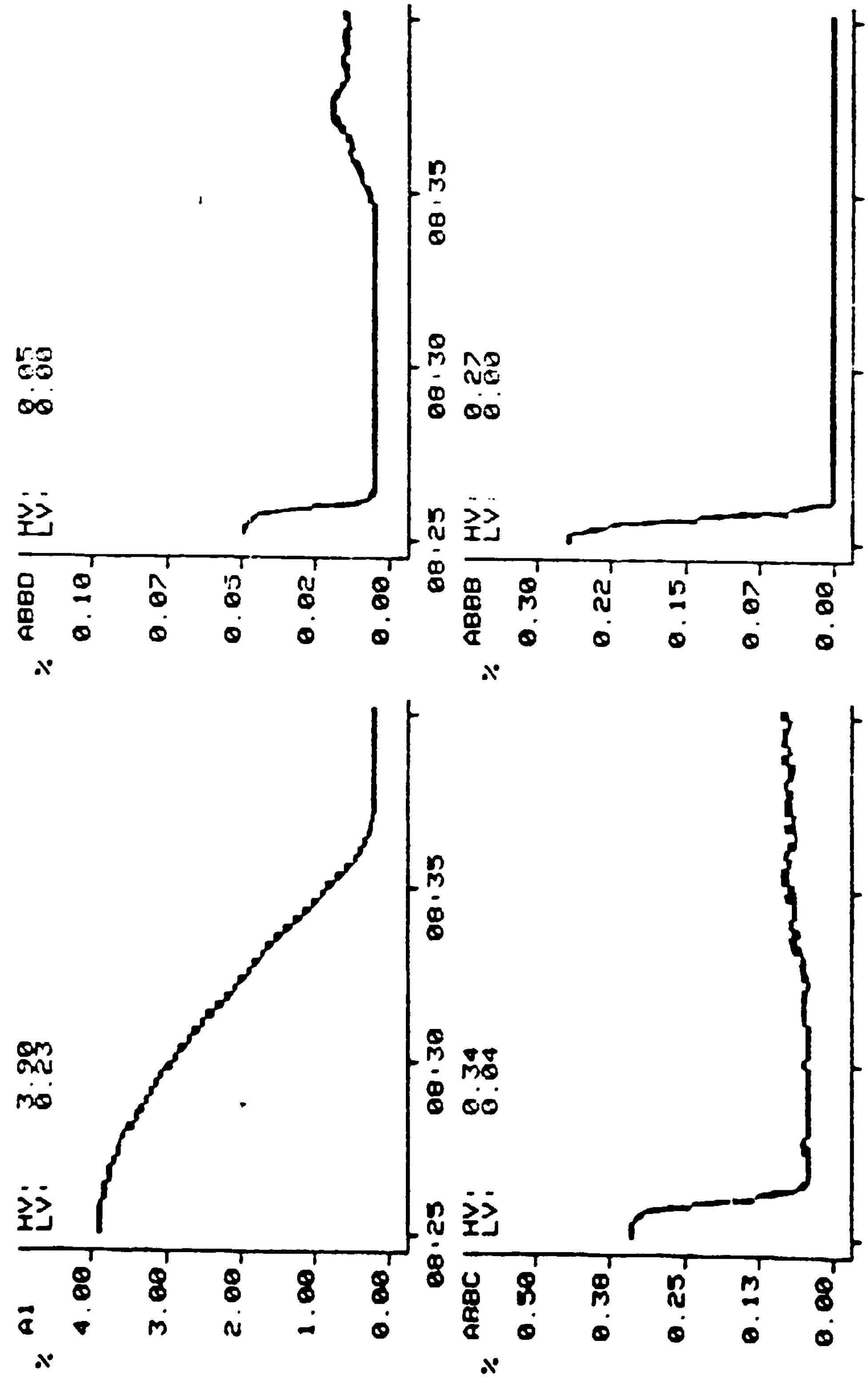
CONTINUOUS HISTORY OF OXYGEN YIELD (RO2M). CARBON ANALYSIS (A1). DECARBURIZATION RATE (YAAG) AND SLAG WEIGHT (WTBS)...



NOTE. CHARGE S1375 AT MEFOS. CURVES ARE HARD-COPIES OF ONE OPERATOR GUIDANCE DISPLAY WHICH IS UPDATED ON-LINE AT 15 SEC INTERVALS.

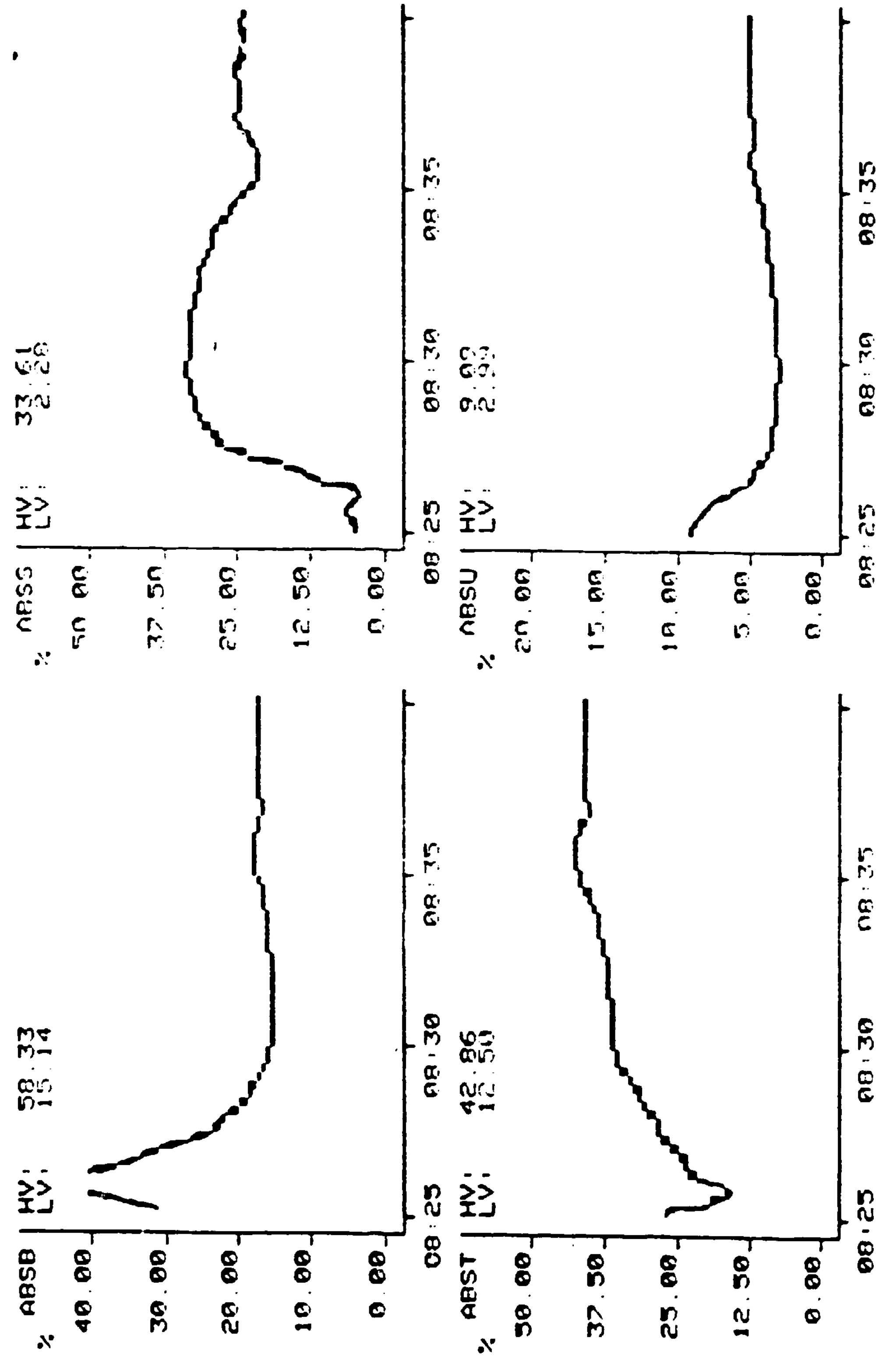
APPENDIX 6

CONTINUOUS HISTORY OF BATH ANALYSIS. %C (A1). %P (ABBD). %MN (ABBC) AND % SILICON (ABBB)........



NOTE. CHARGE S1375 AT MEFOS. CURVES ARE HARD-COPIES OF ONE OPERATOR GUIDANCE DISPLAY WHICH IS UPDATED ON-LINE AT 15 SEC INTERVALS.

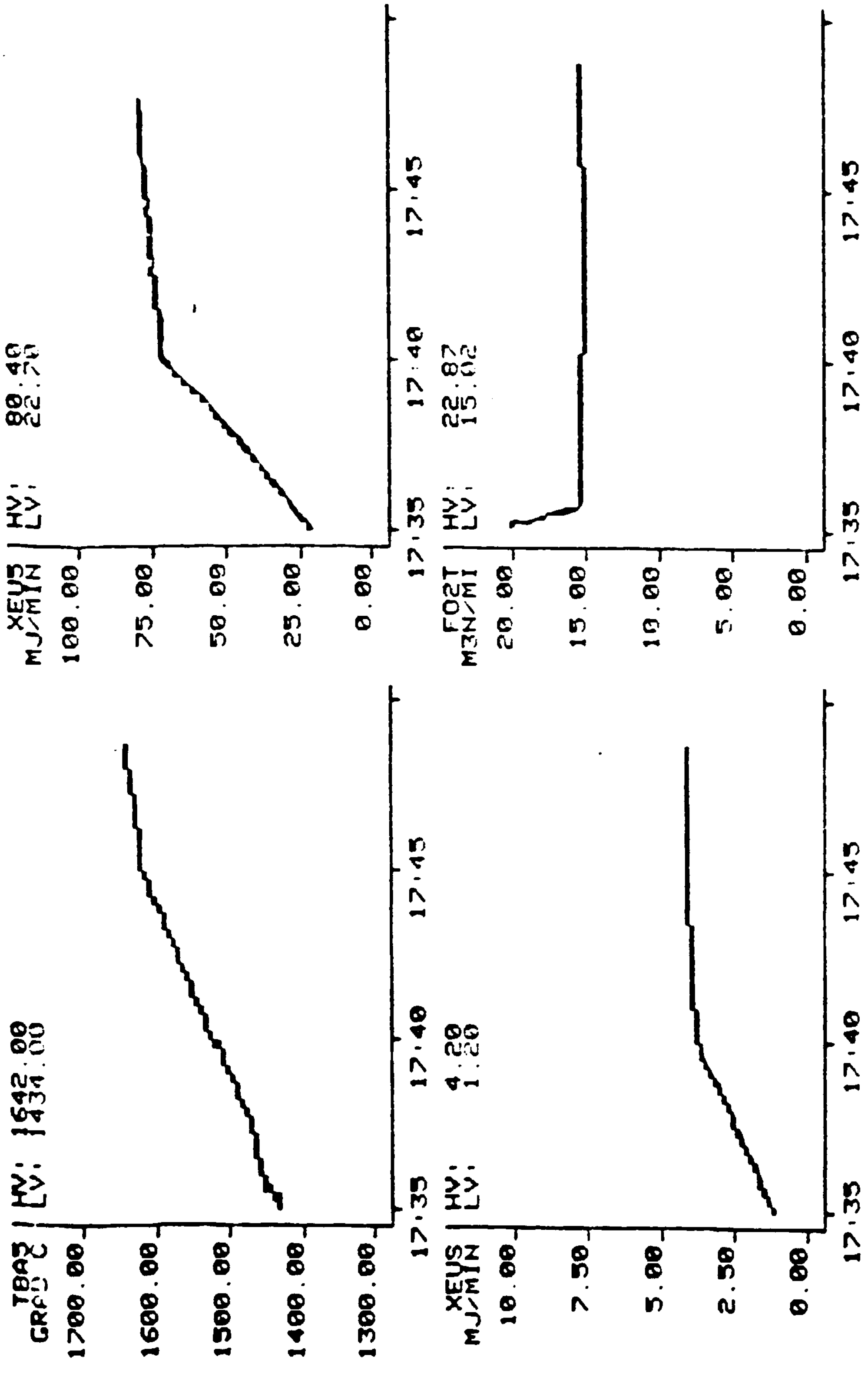
CONTINUOUS HISTORY OF SLAG ANALYSIS. SIO_2 (ABSB). FEO (ABSS). CAO (ABST) AND MGO (ABSU).......



NOTE. CHARGE S1375 AT MEFOS. CURVES ARE HARD-COPIES OF ONE OPERATOR GUIDANCE DISPLAY WHICH IS UPDATED ON-LINE AT 15 SEC INTERVALS.

APPENDIX 8

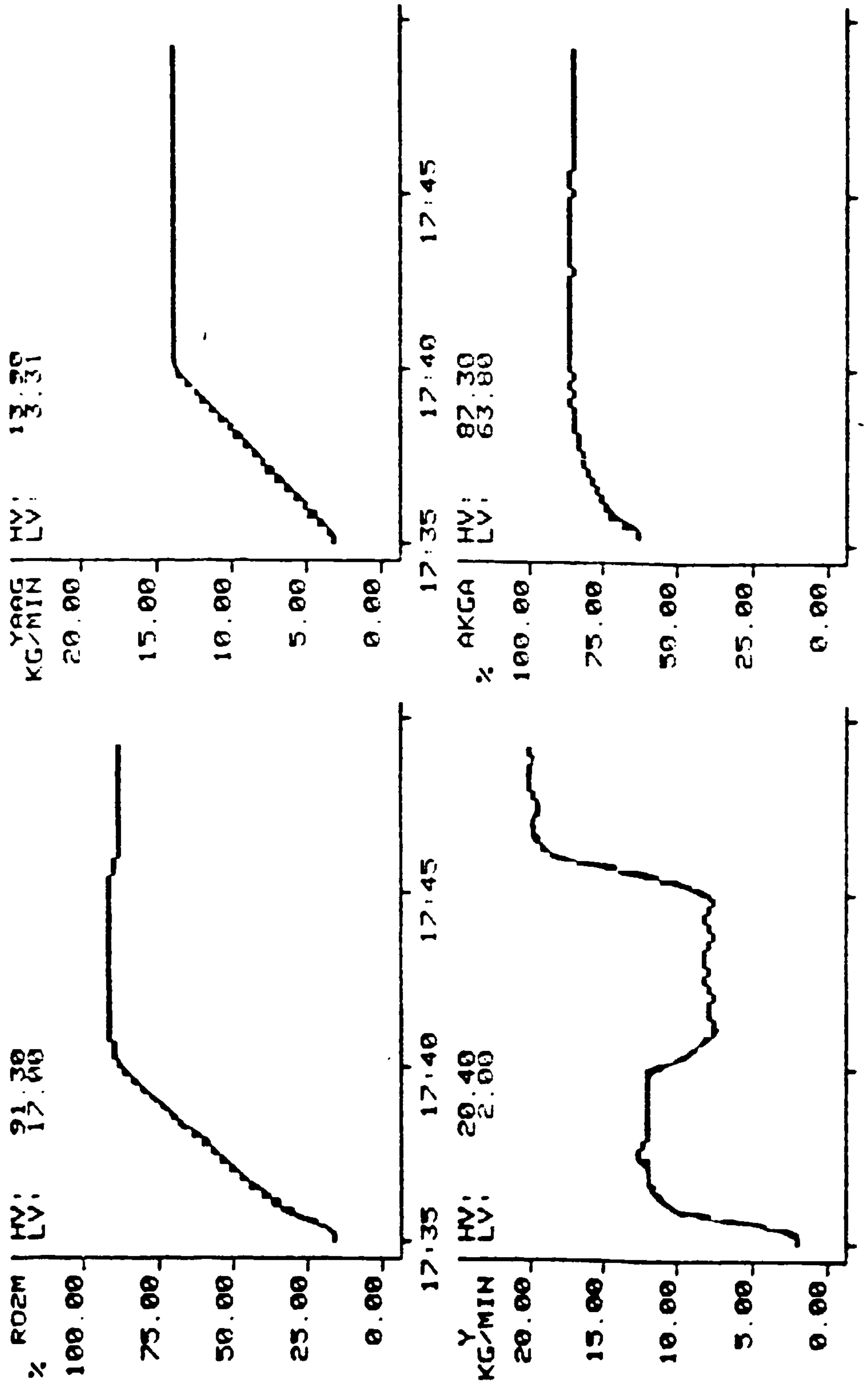
CONTINUOUS HISTORY OF BATH TEMPERATURE (TBA5). TOTAL HEAT FLOW WITH WASTE GAS (XEU5). HEAT FLOW WITH DUST (XEUS) AND TOTALLY INPUT FLOW RATE OF OXYGEN (ALL GASES AND MATERIALS)



NOTE. SIMULATED DATA. CURVES ARE HARD-COPIES OF ONE OPERATOR GUIDANCE DISPLAY UPDATED ON-LINE AT 15 SEC INTERVALS.

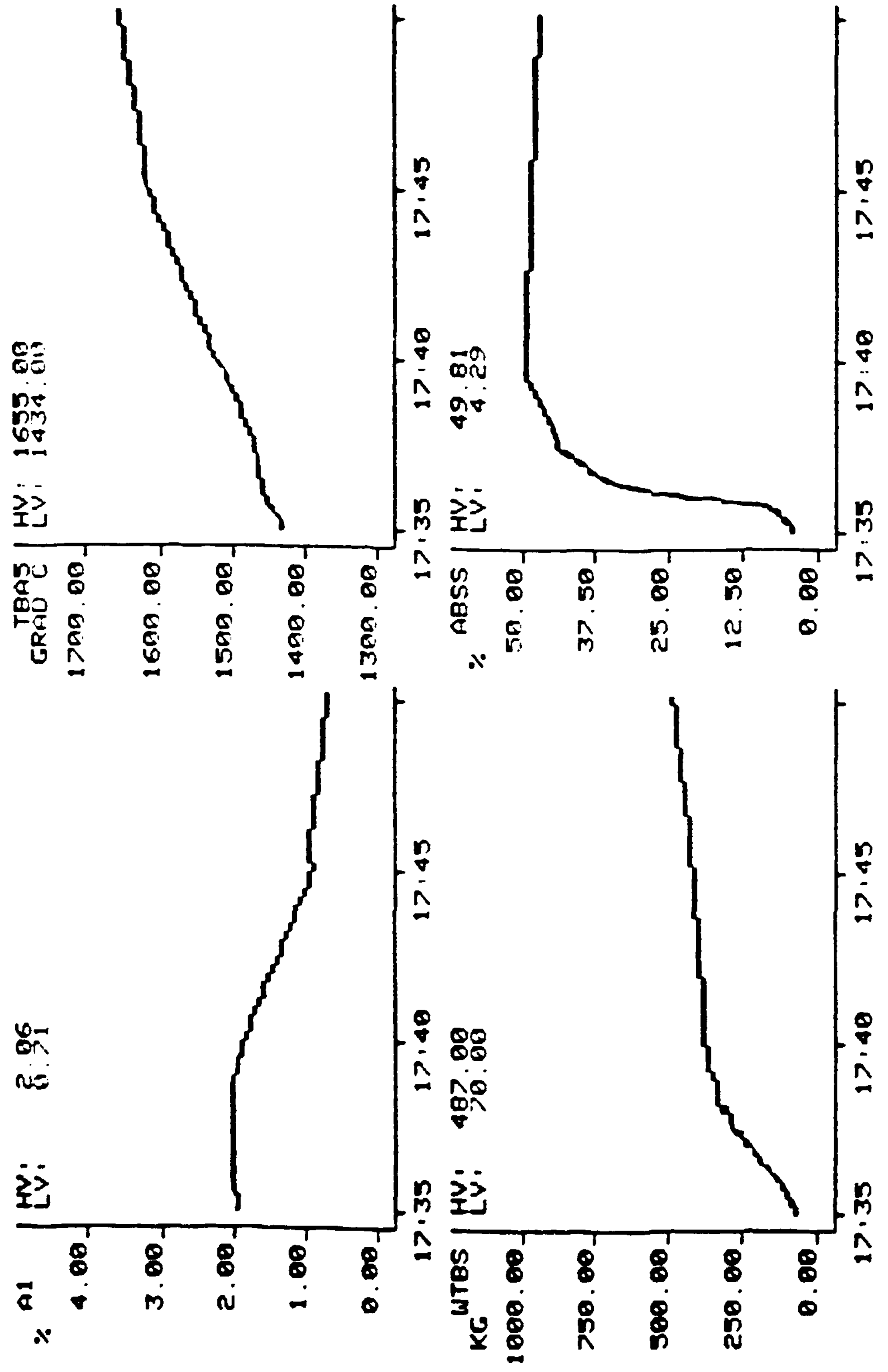
APPENDIX 9

CONTINUOUS HISTORY OF OXYGEN YIELD (RO2M). DECARBURIZATION RATE (YAAG). MATERIAL INJECTION FLOW RATE (Y) AND PERCENTAGE OF CO IN CONVERTER GAS........



NOTE. SIMULATED DATA. CURVES ARE HARD-COPIES OF ONE OPERATOR GUIDANCE DISPLAY WHICH IS UPDATED ON-LINE AT 15 SEC INTERVALS.

CONTINUOUS HISTORY OF CARBON ANALYSIS (A1). BATH TEMPERATURE (TBA5). SLAG WEIGHT (WTBS) AND FEO IN SLAG..........



NOTE. SIMULATED DATA. CURVES ARE HARD-COPIES OF ONE OPERATOR GUIDANCE DISPLAY WHICH IS UPDATED ON-LINE AT 15 SEC INTERVALS.

Appendix 6

MEFOS
METALLURGISKA
FORSKNINGSSTATIONEN

Forskningsuppgift.	Konto:	Datum.	Reg nr:
UNIDO/INDIA	4446	1985-03-14	MF85021

SUBJECT: DP/IND/81/036 - CONTRACT NO 84/66 - EXPERT STUDIES

4. REFRACTORY TECHNOLOGY

b'

Bodil Dahlberg

ELLTRYCK Luleå

Postadress
MEFOS
Box 812
951 28 Luleå

Telefon
0920-556 40

Telex
80482 MEFOS S

Bankgiro
758-6555

Postgiro
6 18 00-9

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APPENDIX

4.1 INTRODUCTION

Since the early days of the oxygen steelmaking converter process, the refractory lining has been the subject of the devoted attention of the steelmaker and the refractories engineers. Looking in retrospective there is much in the lining of converters, which seems constant

- a wear lining of large blocks of basic material, magnesite or dolomite, installed without mortar.
- a safety lining also consisting of basic brick
- a taphole made of fired magnesite

Impressive is the progress made in achieving longer life of the wear lining and lower consumption of refractory material per ton of steel. The factors which brought about these results are:

- improved brick quality
- better control of the steelmaking process
- extensive use of gunning repair

During 1970's different combined blowing techniques have been introduced all over the world. This has led to further development of refractories, i.e. permeable elements, tuyere bricks and changes in lining pattern.

The aim with this report is:

- to present refractory techniques in combined-blown converters in Japan and Europe
- to commment the Indian conditions in the field of converter practices
- to give recommendations regarding lines of development to achieve improved practice in India.

4.2 REFRACTORY TECHNIQUES IN CB-CONVERTERS IN JAPAN, SCANDINAVIA AND THE REST OF EUROPE

4.2.1 Economic considerations

Steel demand and plant environment are the two main factors which determine the optimum converter lining life and which directly influence lining practice. Within the limits of such a predetermined lining life, the refractory costs must be minimized by achieving a balanced wear profile at the end of the furnace campaign. This is generally attained by the use of a composite wear lining with several refractory grades and wall thicknesses chosen according to the different wear mechanisms and wear rates encountered in the converter.

Although there is no uniform pattern of lining practice, it is generally possible to distinguish two main situations depending on whether there is an adequate or an insufficient availability of steel-making equipment.

Steelplant with adequate vessel availability

There are several situations where vessel availability is of little concern. This is especially the case:

- when steel demands is low
- when raw iron capacity is insufficient
- in plants with interchangeable vessels
- in plants with only one out of two fixed vessels in operation

Under these conditions, downtime due to relining, maintenance or vessel replacement has little or no influence on total production. The main aim will therefore be to select refractory grades which give a minimum cost per ton of crude steel. Under these circumstances it is possible to adopt two diametrically opposed lining solutions.

The first so-called economic solution is to select the cheapest lining capable of achieving the life level necessary. Due to the difference in price between dolomite and magnesite refractories such lining will be based on either 100%-dolomite or dolomite with a dolomite-magnesite or magnesite reinforcement of high wear areas. Figure 1 shows a dolomite based lining of a 60 t LD converter with a fairly straight forward design.

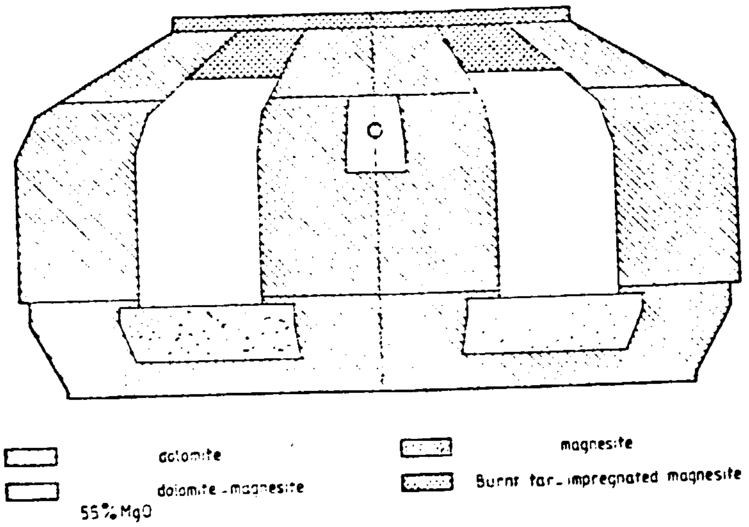


Figure 1 - Dolomite based lining of a 60 t LD-converter /1/.

A more complex zoned lining of a 240 t LD converter with a higher proportion of magnesite is depiced in Figure 2 .

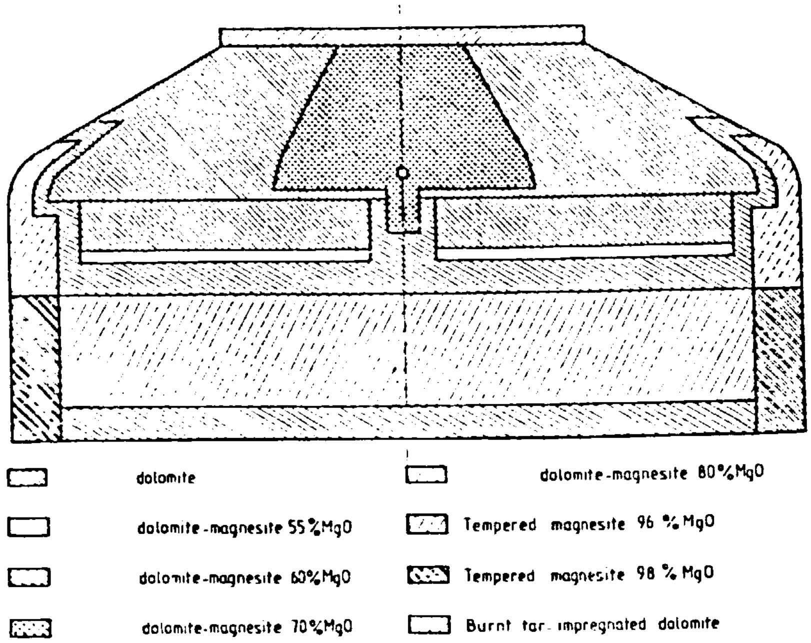

dolomite
dolomite-magnesite 55%MgO
dolomite-magnesite 60%MgO
dolomite-magnesite 70%MgO
dolomite-magnesite 80%MgO
Tempered magnesite 96 % MgO
Tempered magnesite 98 % MgO
Burnt tar- impregnated dolomite

Figure 2 - Dolomite based lining of a 240 t LD-converter /1/.

Another solution to achieve minimum refractory cost is to adopt a high performance lining based on more expensive magnesite and to aim for converter lives considerably extended beyond actual requirements. Comparisons have shown that campaigns with magnesite based linings must be about 3-5 times longer than those with dolomite linings in order to attain equal costs. This is due to higher initial costs for magnesite linings, dolomitic lime practice and a certain amount of gunning maintenance.

Steelplant with insufficient vessel availability

There are many situations when a high converter availability becomes of prime concern, for instance:

- in periods of high steel demand
- when the steelplant constitutes a production bottleneck

- when production is to be made with two out of three or three out of four converters
- when several steelmaking facilities exist with a marked difference in production cost

In all these cases it is necessary to minimize downtime and production loss by maintaining an optimum product flow from converters to reheating furnaces. In these plants linings based on the highest quality refractories will be required and downtime due to gunning will be avoided as much as possible. Such high performance lining based on magnesite and balanced wear is generally obtained by the use of magnesia-graphite in high wear areas such as the trunnions and the slag line. An example of a 350 t LD converter lining is shown in Figure 3. Converters with mangesite and magnesite-graphite linings generally achieve about 600-1500 heats with only minimal gunning maintenance (0.1-0.3 kg/t steel).

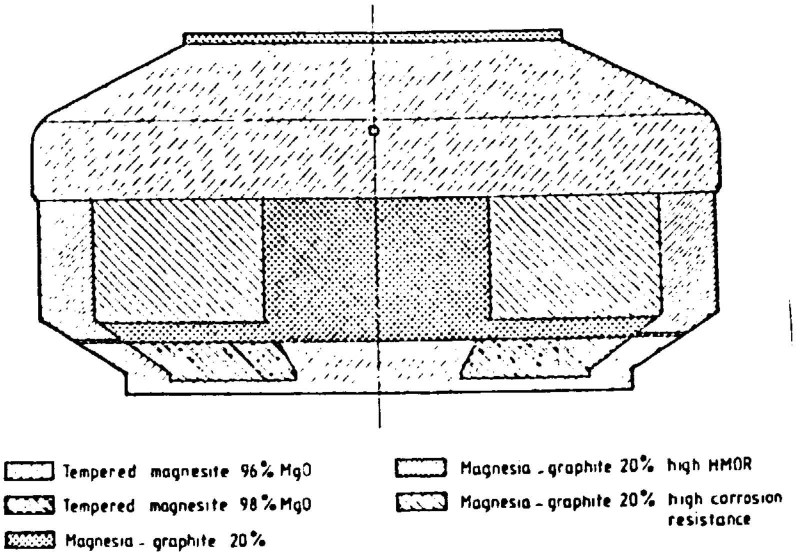

Tempered magnesite 96% MgO
Tempered magnesite 98% MgO
Magnesia - graphite 20%
Magnesia - graphite 20% high HMOR
Magnesia - graphite 20% high corrosion resistance

Figure 3 - Magnesite based lining of a 305 t LD converter /1/.

4.2.2 Lining practice in Japan

The applications of MgO-C-bricks in Japanese converters began rather recently; the first being in tuyeres of Q-BOP in the Chiba Works of Kawasaki Steel in 1978. Today mag-carbon bricks are the dominant lining material in Japanese converters, in some cases up to 90% of the refractories are MgO-C-bricks. Figure 4 shows the development of the unit consumption of converter refractories in Japan.

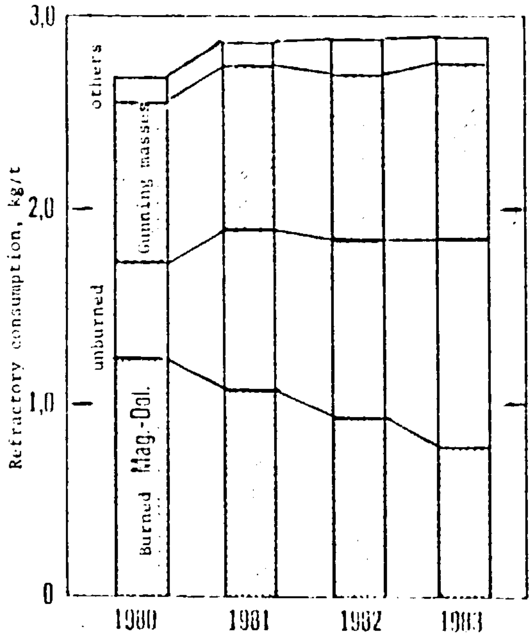


Figure 4 - Development of the unit consumption of converter refractories (average of all Japanese converters) /2/.

An example of an converter lining constructed of MgO-C-bricks is shown in Figure 5. It is a 250 t combined blown converter (STB) from Kashima Steel Works.

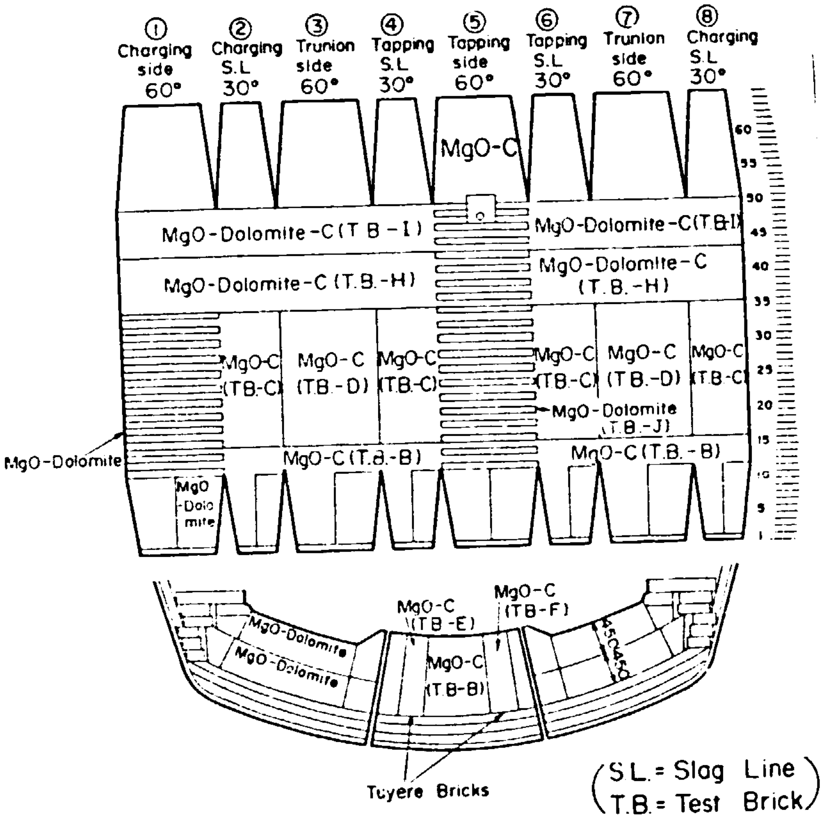

①
Charging side 60°
②
Charging S.L 30°
③
Trunion side 60°
④
Tapping S.L 30°
⑤
Tapping side 60°
⑥
Tapping S.L 30°
⑦
Trunion side 60°
⑧
Charging S.L 30°
MgO-C
MgO-Dolomite-C(T B - I)
MgO-Dolomite-C(T.B-I)
MgO-Dolomite-C (T.B.-H)
MgO-Dolomite-C (T.B.-H)
MgO-C (TB-C)
MgO-C (TB-D)
MgO-C (TB-C)
MgO-C (TB-C)
MgO-C (T.B.-D)
MgO-C (TB-C)
MgO-Dolomite (T.B.-J)
MgO-Dolomite
MgO-C (T.B.-B)
MgO-C (T.B.-B)
MgO-Dolomite
60
55
50
45
40
35
30
25
20
15
10
5
1
MgO-Dolomite
MgO-Dolomite
MgO-C (TB-E)
MgO-C (TB-F)
MgO-C (TB-B)
450450
Tuyere Bricks
(S.L. = Slag Line
T.B. = Test Brick)

Figure 5 - Schematic diagram of converter lining /3/.

Another example of a Japanese combined blown converter is shown in Figure 6. The example is from Kokogawa Works where the main lining material still is unburned magnesia-dolomite brick. Only 5% of the total lining is MgO-C-brick. The lining life of the converter is about 1000 heats without any hot gunning repair.

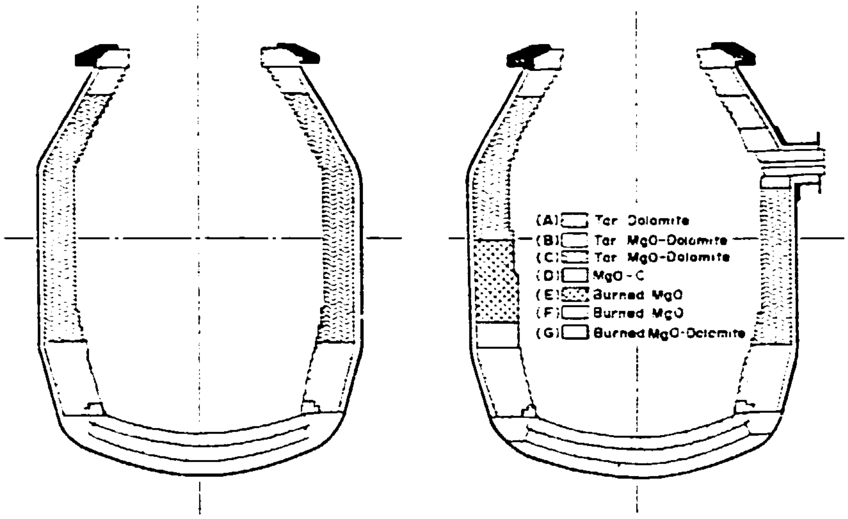
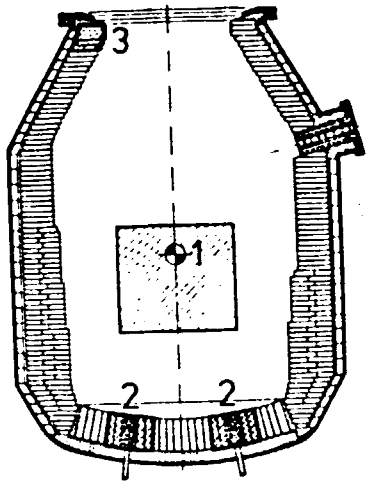

(A) Tar Dolomite
(B) Tar MgO-Dolomite
(C) Tar MgO-Dolomite
(D) MgO - C
(E) Burned MgO
(F) Burned MgO
(G) Burned MgO-Dolomite

Figure 6 - Lining profile of 240 t LD-OTB converter at Kokogawa Works /4/.

4.2.3 Lining practice in Europe

European converters are today practically exclusively lined with pitch-bonded basic brick and monolitics. Various types of refractories are employed, such as dolomite, dolomite enriched with magnesite, magnesite or more recently mangesia-graphite. The relative amount of dolomite or magnesite refractories in Europe is 50/50 but it varies considerably from one region to another. The converters in France, United Kingdom, Italy and Sweden are mainly lined with magnesite whereas linings of converters in Belgium, Norway and Finland are predominantly composed of dolomite. The application of mag-carbon bricks in European converters is normally limited to the area around the purging elements, the trunnion area and the mouth on the slagging side, see Figure 7.



1. Trunnion
2. Purging element
3. Mouth

Figure 7 - Application of mag-carbon bricks in European converters /5/.

One exeption is the United Kingdom where mag-carbon-bricks are the prevalent lining material.

In Figure 8 is a typical magnesite lining of a 120 t LBE-converter.

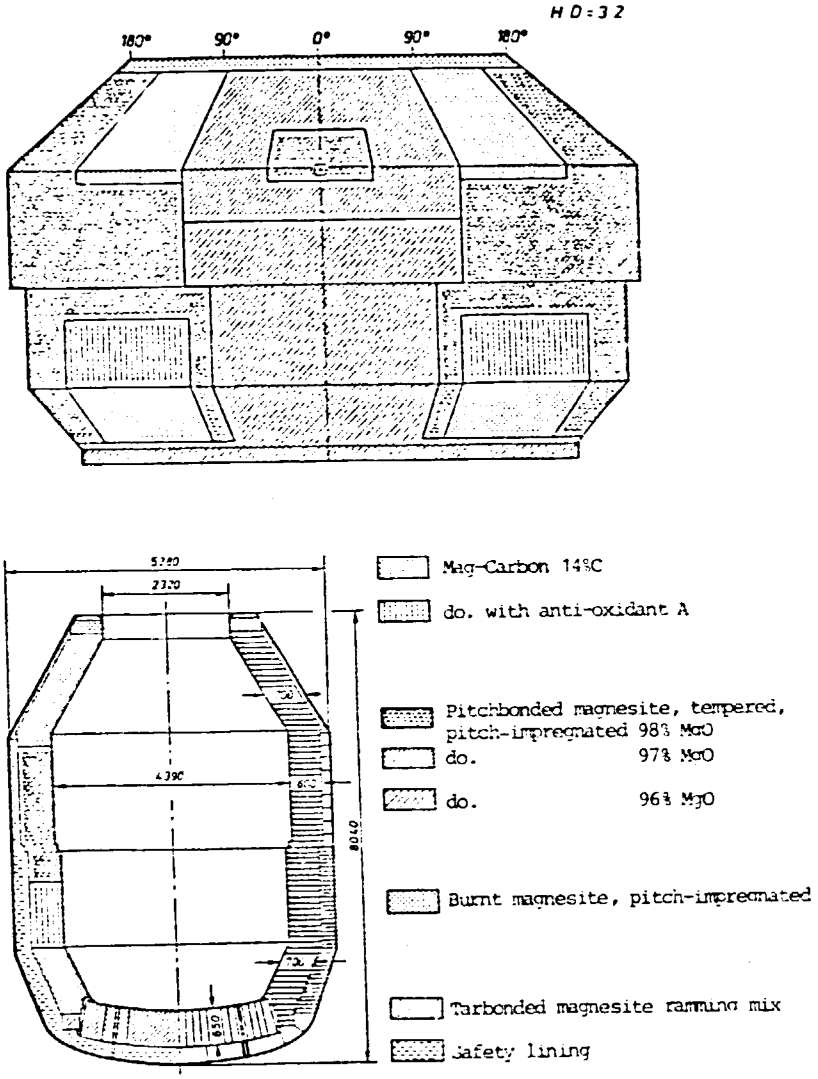

H D=3 2
180°
90°
0°
90°
180°
5280
2320
4390
600
8040
650
Mag-Carbon 14%C
do. with anti-oxidant A
Pitchbonded magnesite, tempered, pitch-impregnated 98% MgO
do. 97% MgO
do. 96% MgO
Burnt magnesite, pitch-impregnated
Tarbonded magnesite ramming mix
Safety lining

Figure 8 - Magnesite based lining of a 120 t LBE-converter /6/.

4.2.4 Lining practice in Scandinavia

In Sweden the converters are equipped with inert gas stirring, the LBE-process. The lining material is or will be 100% magnesite due to very high steel demand.

Table 1 - Lining practice in Swedish LBE-converters.

	SSAB Luleå	SSAB Oxelösund	
		Today	Planned
Refractories	Pitch-bonded magnesite	Pitch-bonded dolomite (1) and magnesite (2)	Pitch-bonded magnesite
Thickness, Bottom, mm	750 x)	800 (2)	800 x)
Barrel, mm	650	650 (1)	650
Cone, mm	650	500 (1)	500
Panels, mm	-	650 x) (2)	650 x)
Average lining life, heats	1 150	600	1 050
Converter size, tons	105	180	180

x) higher quality

Spiral lining is used in both steel-plants.

In Norway the 75 t converters at Norsk Jernverk in Mo i Rana is equipped with inert gas purging through tuyeres. The lining material has up to now been pitchbonded magnesite in the bottom (500 mm) and pitch-bonded dolomite in the barrel. Due to very little wear of the bottom they are now changing over to ceramic bonded dolomite bottom and in the future the thickness will eventually be decreased to 350 mm which is the thickness before the CB-process was installed. The wear rate in the cone has increased after CB was introduced. Change over to ceramic bonded dolomite will hopefully solve that problem. Increased wear in the cone can be a result of higher lance practice and/or that the bath level is higher up in the barrel due to increased bottom thickness.

4.2.5 Lining maintenance

Time taken during normal production for refractory maintenance such as repiping of tapholes and for slagging or gunning will result in lost production. Except for taphole maintenance, which is avoidable, the other maintenance time often represents a reduction of available time that has to be balanced by longer lining life.

During the late 1970's and the beginning of the 80's there was a trend towards extended use of monolitic refractories in Japan and Europe. Programmed gunning became very popular especially in Japan. Semiwet and wet gunning had a lot of disadvantages which led to development of different flame-gunning techniques. Experiences with flame-gunning in Japan showed that due to high costs the technique will be limited to production of high quality steel.

The trend today in Europe as well as in Japan is that gunning is carried out only when need arises and is concentrated on the area or areas where the working lining is breached or known to be very thin.

4.3 COMMENTS ON INDIAN CONDITIONS IN THE FIELD OF CONVERTER PRACTICES

4.3.1 Production of tarbonded dolomite bricks

Raw material and sintering

The raw dolomite used for brick making in Bokaro Steel Plant is of a poor quality. The total flux content in the sintered product is on average 6.8%.

In Europe the general opinion is that the total flux content should not exceed 3.5 wt-%. At the same time the grain density shall exceed 3.00 g/cm^3.

The effect of the chemical quality on the calculated liquid content of various dolomites is shown in Table 2. It can be seen that the dolomite, type A, with a flux content similar to the dolomite used in Bokaro Steel Plant (Bhutan), shows a marked increase in liquid content over the other dolomites (B and C) at temperatures above 1600°C. It is obvious that at tapping temperatures of 1650°C, which is similar to the tapping temperatures at Bokaro Steel Plant, the liquid content will be very high. A further increase in the liquid content will occur at 1700°C because of increased solubility of the primary CaO and MgO phases. Tapping temperatures of 1700°C will be a reality in India when ladle metallurgy and continous casting are introduced in the future.

Table 2 - Calculated liquid contents of different dead burnt dolomites in the 1350-1700°C temperature range /7/.

Dolomite type	Impurity content (Weight %) (Loss free)			Calculated liquid content (Wt. %) at °C					
	SiO_2	Al_2O_3	Fe_2O_3	1350	1400	1500	1600	1650	1700
A	2.7	1.2	1.6	6.9	7.2	7.8	9.7	12.2	15.6
B	1.0	0.45	2.0	5.6	5.8	6.4	7.9	8.2	8.4
C	0.8	0.4	1.2	3.7	3.9	4.2	5.2	5.9	6.1

The properties of West Germany (Wülfrath) and British (Steetley) dolomite sinter for brickmaking are shown in Table 3. As a comparison the Indian dolomite used at Bokaro Steelplant is presented.

Table 3 - Properties of different dolomite sinter.

	$\%SiO_2$	$\%Al_2O_3$	$\%Fe_2O_3$	%Total flux	Grain density (g/cm^3)
Wülfrath	<1.5	<1.0	<1.0	<3.5	3.1
Steetley	0.8	0.4	1.2	2.4	3.20-3.25
Bhutan	3.0	2.0	1.8	6.8	2.9-3.15

In Europe it is generally believed that the grain density should not be lower than 3.00 g/cm^3.

The German dolomite is produced in a rotary kiln with a maximum temperature of approx. 2000°C.

In the UK the two stage firing process is used. This means that the raw dolomite is fired in two steps, first calcined at 1400°C, thereafter the calcined dolomit is crushed and briquetted and finally fired at 1950°C. Rotary kiln is used in both steps. The reason for adopting this process is because it is the only possibility to get such a high grain density with such a low flux content.

Though the Indian dolomite has a high flux content it is hard to reach an acceptable grain density (lower limit at Bokaro Steel Plant 2.8 g/cm^3). The maximum temperature in the rotary kiln is 1700°C which seems too be to low though the energy input in Bokaro is high compared to German praxis, see Table 4. Preheating of the fuel and eventually oxygen enrichment of air for combustion plus increasing the zone of combustion should be considered.

Table 4 - Comparison of energy input/t sinter for different producers.

	Energy input/ton sinter GJ	toe[1])	Note
Bokaro Steel plant	15.8	0.38	Preheated air
Wülfrath	9.15	0.22	Preheated sinter Preheated air, 500°C
Sweden, 1978	11.7	0.28	Preheated oil, 130°C

1) equivalent ton oil = 41.9 GJ

Brickmaking

The exact composition of grain sizes for brick-making is a knowledge which every brickmaker today keeps as a secret. A typical sieve analysis for production of tarbonded dolomite is shown in Table 5. As a comparison the sieve analysis from Bokaro Steel Plant is shown as well as the sieve analysis for tarbonded dolomite bricks produced in Sweden in 1978.

Table 5 - Typically sieve analysis for production of tarbonded dolomite bricks.

Information from literature		Bokaro Steel Plant		Sweden 1978	
mm	wt-%	mm	wt-%	mm	wt-%
4.7-6.4	25	3-8	35-40	7-10	20
0.6-4.7	30	1-3	10-15	2-7	40
0.2-0.6	10	C-1	50	0-2	20
0.074-0.2	5	-0.1	10-20	-0.5	20
-0.074	30				

The binding agent for production of unburned bricks in Europe is exclusively pitch. For production of conventionally pitch-bonded bricks the amount of binding agent is 4-5%, (residual carbon content 2%). Synthetic resin is the latest binding agent used in magnesite bricks in order to increase residual carbon content (approx. 5%). Due to very high costs it is not yet used in dolomite brick production.

Sucessful trials with adding black and graphite to pitch bonded dolomite have been done in Europe.

Bricks are produced by moulding a mixture of heated pitch and dolomite at high pressure in hydraulic presses, $P>100$ N/mm^2. Some producers are using vibration moulding under low pressure, $P<1$ N/mm^2. **The advantage** with the latter method is said to be that the risk of grain fracture is totally excluded.

Tempering of pitchbonded bricks in order to improve both hydration resistance and carbon retention is done by passing them through a tunnel kiln having a temperature of 250-400°C. The residence time is typically about one day. Immediately after the tempering the bricks are sprayed with tar and palletized with a polythene wrap to prevent moisture absorption.

Physical properties of German pitch bonded bricks compared to Indian ones are shown in Table 6.

Table 6 - Physical properties of German and Indian bricks.

	Wülfrath	Didier	Bokaro Steel Plant
Bulk density (g/cm^3)	2.85-3.00	2.87	>2.85
Total porosity (% by volume)	6-10	-	8-10
Cold crushing strength (kp/cm^2)	>294	540	>60

4.3.2 Lining techniques

Double layer lining which is praxis in Bokaro Steel Plant has the following defects:

1 Since the joint part of outside and inside brick is unstable structurally the inside brick will fall off in the middle of a campaign. The conditioning of falling at the joint is shown in Figure 9.

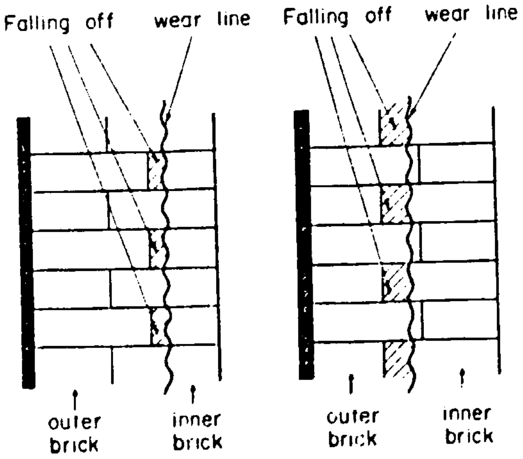

Falling off
wear line
Falling off
wear line
outer brick
inner brick
outer brick
inner brick

Figure 9 - Falling off-model of inner bricks at boundary part /3/.

2 If bricks with different taper are used, the joint will not point accurately to the center of the furnace, which also will cause falling of bricks.

3 As shown in Figure 10, many triangle joints will appear at the back of the bricks and in the space between inside bricks and outside bricks. This can cause penetration of metal during operation and falling of bricks when residual thickness of bricks becomes thin.

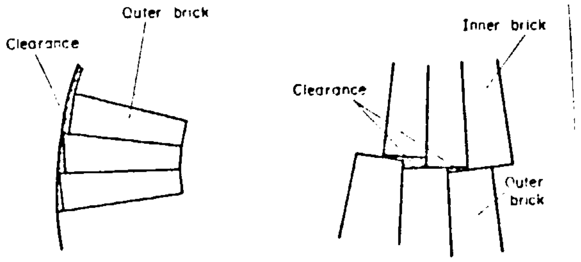


Figure 10 - Example of clearance for lining bricks /3/.

In the Bokaro Steel Plant the first defect has been utilized to decide when it is time for relining the converter. This will not be necessary any longer since equipment for laser beam measurement of lining thickness (IMS1600 from Geotronics in Sweden) has been bought. It is therefore recommended that single layer lining with long bricks will be adopted, provided that long bricks can be produced.

Long bricks are unfortunately very heavy and problems with lifts can arise.

In order to decrease time needed for lining the converter spiral lining technique can be adopted. Another positive result is that joints between first and last brick in every ring is avoided. The joints could be a weak point in the lining if some kind of monolitic refractory is used.

4.3.3 Operating parameters

Although refractory selection, properties and design play critical roles in determining lining life, operational practices can have a far greater effect on refractory performance.

For Indian conditions the following operating parameters are of special importance for the poor lining life in the converter:

- Hot metal analysis, 1.4-2.2% Si
- Poor lime quality
- High reblowing frequency

The high silicon content leads to a big slag volume and a very aggressive slag in the first part of the blowing. If in addition the slag formation is slow due to bad lime quality this will result in a high lining wear rate. The reblowing frequency can be decreased by adopting process control.

4.4 RECOMMENDATIONS REGARDING LINES OF DEVELOPMENT TO ACHIEVE IMPROVED PRACTICE

4.4.1 BOF General practice

In order to increase converter lining life in the Bokaro Steel Plant with maintained dolomitic lining we recommend the following steps:

1 For brick making a dolomite with a flux content less than approx. 3.5 wt-% should be used.

2 Maximum sintering temperature must be raised to about 1900°C to reach a grain density of >3.10 g/cm^3 for the dolomite mentioned above.

3 Due to high atmospheric humidity in India the storing time of dolomite sinter must be minimized.

4 Use a binding agent that gives a higher residual carbon content in the bricks, i.e. pitch or synthetic resin + extra carbon (graphite etc).

5 Install tempering of the bricks combined with tar spraying afterwards.

6 Use single layer lining technique if it is possible to produce and line long bricks (heavy lifts).

7 Improve lime quality; lime stone quality as well as sieving and storing of lime.

8 Introduce pre treatment of hot metal; desiliconization.

9 Decrease reblowing frequency; process control.

4.4.2 Permeable block

Permeable elements for inert gas bubbling through converter bottom are mainly of four types. The inert gas is brought into the melt through:

1) Slits across the bricks - Veitcher Magnesitewerke AG/Arbed (LBE-process)

2) Slit between the sheet iron cover and the brick - Magnesital Feuerfest, Hoogovens Ijmuiden/BSC

3) Porous plug with directional porosity - Radex

4) Multiple hole plug (stainless steel pipes) - Nippon Kokan KK

The different types of peremable blocks on the market will be presented below.

Veitcher Magnesitewerke AG/Arbed (LBE)

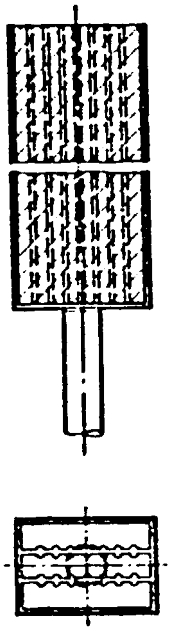


Figure 11 - LBE-permeable element.

Figure 11 shows the LBE-permeable element produced by Veticher Magnesitwerke AG. The refractory materials in the canned bricks have the following characteristics:

Magnesia-carbon brick with 90% fused magnesia, containing anti-oxidants (Mg, Al or Si), resin bonded.

Chemical_Analysis (MgO-part)

MgO	97.0 weight-%
Al_2O_3	0.1 -"-
Fe_2O_3	0.2 -"-
SiO_2	0.7 -"-
CaO	1.8 -"-

Bulk_density, original 2.86 g/cm^3

after firing in reducing atmosphere at 1000°C 2.81 g/cm^3

Apparent_porosity, original 3.0 vol-%

after firing in reducing atmosphere at 1000°C 9.0 vol-%

Crushing_strenght, original 35 N/mm^2

after firing in reducing atmosphere at 1000°C 34 N/mm^2

Residual_carbon,

after firing in reducing atmosphere at 1000°C 18 Wt-%

Temperature (°C)	500	750	1000	1200	1400
Lin. Therm Expansion (%)	0.42	0.68	1.00	1.32	1.60
Thermal Conductivity (W/mK)	13	13	12	11	10.5

Hoogovens Ijmuiden/BSC

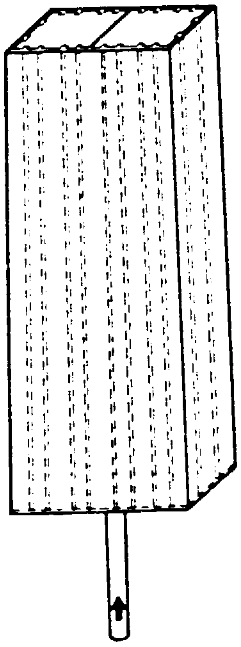


Figure 12 - Canned bricks made from existing bottom bricks.

The canned permeable element are produced from standard bricks, either tempered tar-bonded MgO or magnesia-carbon bricks. The bricks are enveloped by steel plate as shown in Figure 12. Two bricks are positioned within the can. The faces of the bricks towards the can have vertical grooves to adjust the passage of gas.

The wear rate can be reduced by appropriate slagging of the bottom. Slagging is carried out by keeping approximately 3 ton slag in the vessel when the slag is judged to be of acceptable condition. Approximately 300 kg of pebbles (18-20 mm) of uncalcined dolomite are added from the top through a chute. The dolomite pebbles are to be distributed evenly over the canned bricks. During slagging a minimum gas flow rate is maintained. Slagging of bottom is completed by rocking movement of the vessel to homogeneously spread the slag-dolomite.

Slagging is carried out at irregular intervals depending on the result of laser beam measurement. In practice a slagging operation is carried out once per 4 heat.

Radex porous plug with directional porosity

Radex porous plug for inert gas bubbling in LD-converter consists of canned bricks of magnesia-carbon refractory with about 50 mini-tuyeres (ϕ = 1-1.5 mm) through the bricks see Figure 13. The outside dimension of the element corresponds to European standard shape. The maximum length producible is 700 mm. For the introduction of gases the bricks are encased with a metal envelope. Metal sheet in quality SIS2357 having a thickness of 2.5 mm or non-scaling metal sheet, material No 2821 having a thickness of 1.8 mm are used for the metal envelope.

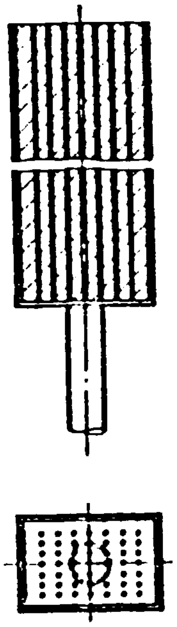


Figure 13 - Radex porous plug.

The porous plug is made from a tempered high grade mag-carbon quality with 100% fused grain. Residual carbon is 15%.

Nippon Kokan KK - MHP

The bottom blowing nozzle developed for the NK-CB-method (CO_2, Ar and N_2 is blown from the bottom) is named multi hole plug (MHP) where a number of pipes are made in magnesia-carbon refractories, see Figure 14.

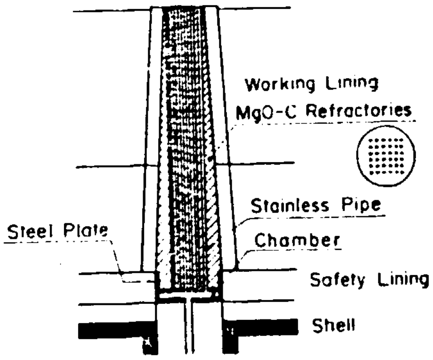

Working Lining
MgO-C Refractories
Stainless Pipe
Steel Plate
Chamber
Safety Lining
Shell

Figure 14 - Schematic diagram of MHP /8/.

The MHP-nozzle is made up of 30-200 stainless steel pipes of 0.5-2 mm inner diameter, the properties of the MgO-C refractories are shown in Table 7.

Table 7 - Properties of MgO-C refractories /8/.

Chemical composition (%)		
MgO		72
C		22
Apparent porosity	(%)	3.9
Bulk density	(g/cm3)	2.91
Cold crushing strength	(kg/cm2)	350
Cold modulus of rupture	(kg/cm2)	150

The MgO-C refractories are composed by mixing magnesia grains and graphite flakes with termosetting resin as a binding agent and formed by isostatic pressing.

In addition to the wear of the nozzle itself, the turbulence of the flow of the molten steel becomes a problem in durability of the joint between the nozzle and its surrounding bricks where the flow of the molten steel becomes markedly turbulent. To prevent and control this problem, the steel pipes of the MHP nozzle are divided into two blowing systems, the outer peripheral blowing system and the inner core blowing system, see Figure 15.

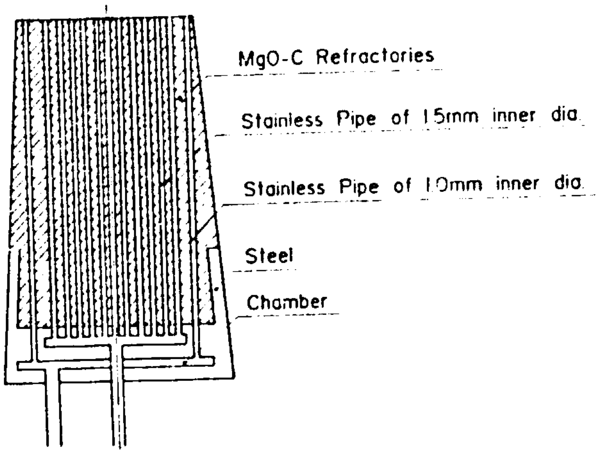

MgO-C Refractories
Stainless Pipe of 1.5mm inner dia.
Stainless Pipe of 1.0mm inner dia.
Steel
Chamber

Figure 15 - MHP-nozzle with two blowing systems /8/.

Recommendations

We recommend that the same lines of developments as Hoogovens Ijmuiden will be chosen i.e. producing permeable blocks out of standard magnesite bricks. Those are available in India and can be cut into correct size. For the introduction of gases a metal envelope of nonscaling steel with necessary joining pipe is needed.

4.4.3 Tuyere based technology

Tuyeres instead of permeable blocks for inert gas bubbling mean no important difference in refractory praxis. Normally for tuyere praxis the wear is concentrated to the tuyere brick due to "back-attack" which means blowing back of the jet and attacking the front surface of the tuyere.

The gas jet forms a cavity in the bath and many bubbles are made on the cavity surface. But occasionally the cavity is constricted close to the tuyere. This continues to develope and sweep away with downward flow. But as this construction is formed the jet is blown back to the front surface of the tuyere. The frequency is several hundred times each minute and the impact force acts on the tuyere refractory.

This phenomenon could be decreased by means of annular tuyeres. The wear rate can be decreased if mag-carbon bricks are used as tuyere bricks.

4.4.4 Test and simultation system

Introduction

The methods for evaluating and testing refractories can be grouped into two categories:

- those necessary for quality control in their manufacture
- those required for evaluating their performance

In spite of many years of study and cooperation, there are still no internationally agreed standard methods for the testing of refractories. For commercial and technical comparisons recourse must be made to methods specified by:

- BSI (British Standard Institution)
- DIN (Deutsche Industrie Normen)
- ASTM (American Society for Testing Materials)
- JIS (Japan Industrial Standard)
- PRE (European Federation of Refractories Producers)
- BCRA (British Ceramic Research Association)

Quality control methods

The following control methods are recommended:

Item	Method
Dolomite acceptance	· X-ray fluorescence analysis · grain composition (screen analysis)
Rotary kilns	· X-ray fluorescence analysis · bulk density · LOI
Storing bunker	· LOI · bulk density
Crushing, grinding, screening plant	· screen analysis
Binding agent	· water content
Bricks	· bulk density · cold crushing strength · residual carbon

Methods for evaluating and testing basic refractories

The properties of refractories can be classified as follows:

Standard test methods available, see Table 8

a) Basic properties:
Porosity, strength, chemical composition etc.

b) Application properties:
Slagging resistance, gas resistance etc.

Large and expensive testing equipment

c) Lining properties:
Temperature distribution, stress distribution etc.

Investigation of used refractories

d) Operational property:
Actual performance in furnace.

For testing tar-bonded and tar-impregnated bricks there are special recommendations, see Appendix 1.

Slag corrosion is one of the most important factors for refractories coming in contact with molten iron and steel. When developing refractories, therefore, priority is given to improvement in resistance to slag corrosion, and various corrosion test methods have been devised. However, conditions causing wear in actual furnace operation are often quite contrary to those obtained through corrosion test. This is because a clear explanation for the wear mechanism in actual furnaces has yet to be revealed. The choice of an appropriate slag corrosion test method, therefore, should be made according to conditions in each actual furnace.

Table 8 - Standard test methods.

Item	Standard Test methods			MEFOS' method
Bulk density	BCRA-75 3:7 BS 1902:1967,4 DIN 51065	ASTM C20-74, C134-70 C357-70, C493-70 PRE/R9 1972	JIS R2205	DIN 51065
True porosity	BCRA-75 3:7 BS 1902:1967,4	DIN 51057, 51065 PRE/R9 1972	JIS R2205	
Apparent porosity	BCRA-75 3:7 BS 1902:1967,4	DIN 51065 ASTM C20-74 PRE/R6 1972	JIS R2205	DIN 51065
Cold crushing strength	BCRA-75 3:9 BS 1902:1976,9	DIN 51067, 1973 ASTM C133-72 PRE/R14	JIS R2206	DIN 51067
Hot modulus of rupture	BCRA-75 3:17, 3:18 DIN 51048, Blatt 1	ASTM C583-67 PRE/R18 1972		DIN 51048
Modulus of rupture	BCRA-75 3:10 BS 1902:1966,13 DIN 51048 1976	ASTM C133/72, 607/67	JIS R2213	DIN 51048
Permanent volume change	BCRA-75 3:8 BS 1902:1966,8 BS 1902:1967,7	ASTM C113/74 DIN 51066 PRE/R19 1972	JIS R2207	DIN 51066
Thermal shock resistance	BCRA-75 3:14 BS 1902:1967,16 DIN 51068, 1976	ASTM C38/68 PRE/R5.1, 5.2	Japan: Acustic Emission Method	DIN 51068
Slag resistance				
Crucible test	DIN 51069,1972		JIS R2214	DIN 51069
Rotary furnace test	BS 1902:5.13			Described in Appendix 2
Induction furnace test	Mainly used in Japan, not standardized			-
Slag drip test	ASTM C768-73			Modified method
Thermal conductivity	BCRA 75 3:16 BS 1902:1967, 10	DIN 51046 ASTM 201-68		Modified method
Thermal expansion	BCRA-75 3:15 BS 1902:1967,17 DIN 51045	ASTM E 228-71		DIN 51045

Rotary slag test

This is a method developed for causing corrosion to occur by constructing a small rotary kiln of which section is hexagonal or decagonal using trapezoid refractory specimens, heating by an acetylene or propane gas burner from one side of the kiln and putting new slag into the rotating kiln from the other side. This method is widely used both by manufacturers and users of refractories since it has advantages as follows:

- a number of specimens can be compared at a time
- a temperature gradient shows in specimens
- fluidity of the slag is achieved
- always fresh slag

On the other hand it has the following disadvantages:

- composition of slag (especially the state of iron oxide) is liable to change since the method generally employs an oxidizing atmosphere
- temperature is difficult to control
- reproducibility and correlation with results obtained in operation of actual furnaces are not as good.

The rotary slag test is newly standardized in the United Kingdom. MEFOS rotary slag test is discribed in Appendix 2.

Figure 16 shows a Japanese variation of the rotary furnace test, known as the arc-heated rotary furnace test, with improvements regarding slag composition and temperature control. The test has become of major interest lately as a non-oxidizing refractory test method.

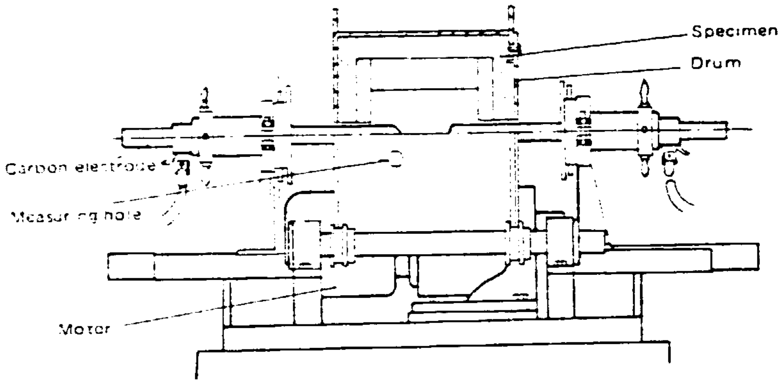

Specimen
Drum
Carbon electrode
Measuring hole
Motor

Figure 16 - Arc heating rotary furnace test /9/.

Induction furnace test

This is a method developed for causing corrosion to occur by setting the refractory specimens in the shape of a polygonal crucible in an induction furnace, putting metal and slag in the crucible, then melting them by induction heating, an outline of which is shown in Figure 17.

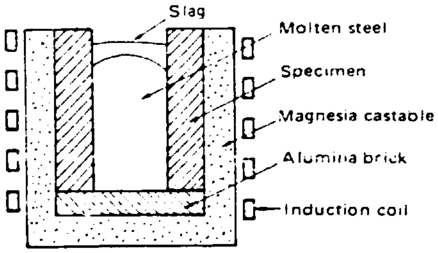

Slag
Molten steel
Specimen
Magnesia castable
Alumina brick
Induction coil

Figure 17 - Induction furnace test /9/.

This method is not necessarily simple in use. With the following advantages, however, this method is considered highly efficient:

- a temperature gradient can be given to a number of specimens with the fluidity of slag and metal
- both atmosphere and temperture can readily be controlled
- rapid and vigorous corrosion occurs at the metal-slag interface
- the method is effective in correlating results with operation of actual furnaces and in reproducibility

Characterisation of the properties of magnesia carbon bricks

Magnesia-carbon bricks differ from other varieties of magnesia bricks by their high carbon content (5-30%), by a generally coarser granulometry and by a more heterogeneous composition. It is possible to use the majority of standard tests if following precautions are taken:

- A very careful sampling because of the heterogenity of the bricks and the risk of segregation of the different phases (magnesia, graphite)
- Coking of the samples in a reducing atmosphere before any trial to eliminate volatile materials and tars
- Protection of the measurement material, especially the thermocouples from carbonaceous pollution.

4.4.5 Refractory lances for HM-treatment

Introduction

The use of the injection process for both iron and steel production has grown rapidly over the last 20 years. A key part of this important process is the injection lance which ensures that powdered reagents are introduced economically and efficiently deep into the molten metal.

An injection lance must withstand high temperature, thermal shock caused by severe and rapid changes in temperature, chemical erosion caused by slag action and mechanical erosion caused by the turbulence of the injection process. A lance must also have strength and rigidity.

A number of causes for lance failure are illustrated in Figure 18.

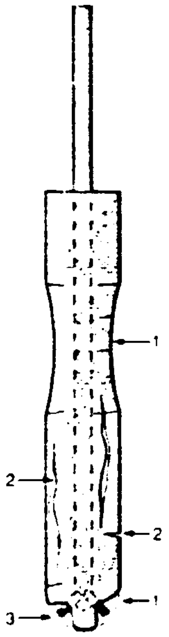


Figure 18 - Causes for lance failure /10/.

These are:

1. Erosion at the slag line or outlet nozzle: this is the most common cause of failure.

2. Mechanical or thermal cracking: the injection process causes vigorous stirring and movement of the ladle's contents. Considerable flexing of the lance leads to premature cracking and failure. Thermal cycling can also affect performance

3. Lance or nozzle blockage: this is caused by irregular and uneven powder flow, a build-up of unreacted powder, chilled metal at the outlet nozzle or mechanical bridgning. The problem is related basically to the injection conditions and the powder's characteristics, and is as critical to lance life as refractory failure.

Lance quality and performance varies between suppliers. Single or multiple use depends on the lance's design, the quality of the materials used, the manufacturing method and the application. Operating conditions such as the molten metal's temperature and the presence/composition of slag have a major influence.

Lance construction

Injection lances in common use are made by three methods:

1. Lances assembled from fireclay and/or high alumina stopper rod sleeves. These lances are cheap in terms of raw materials.

2. Lances designed in sections that can be modified for special stresses.

3. Lances made from cast reinforced monolitic alumina refractory.

Monolitic alumina lances are rapidly replacing lances made from sleeves. A typical lance is a thick walled steel tube approximately 4-6 meters long and 12-30 mm internal diameter. The exterior of this tube is covered by high quality alumina refractory cement to provide insulation and protection from molten metal and slag attack. The lance is oven dried to remove moisture and initiate bonding.

Injection lances can be straight-through design or the material can be directed sideways by a multi-port tip, see Figure 19.

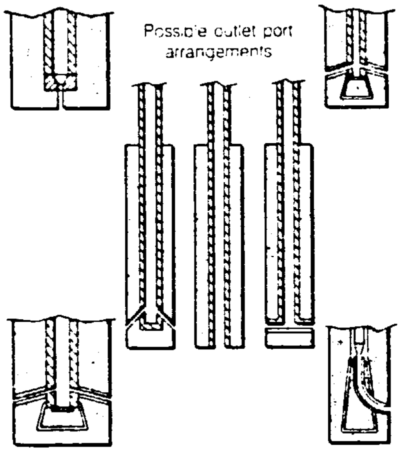


Figure 19 - Possible outlet port arrangements /10/.

The number of outlet ports depends on the type of material injected and ranges from one to four. The highest number of ports is considered best for maximum gas and powder distribution but increases the risk of blockages due to pressure differentials.

The lance tip can be integral with the lance or replaceable. The replaceable tip is preferred because a new tip can be fitted easily and quickly if a blockage occurs.

The advantages for multi-ports are:

- Better powder distribution
- Less turbulence and vibration
- Less blockage

The Foseco lances

Foseco injection lances are medium and high alumina monolitic cast refractory designs produced to exacting specifications. The main parts are shown in Figure 20.

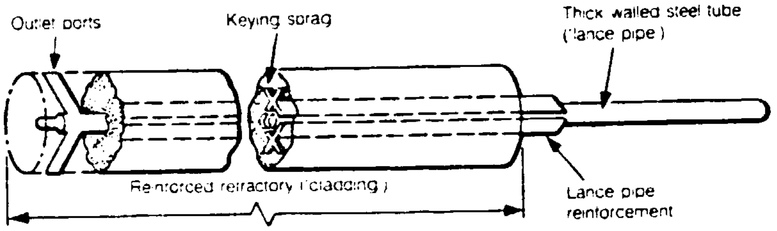

Outlet ports
Keying sprag
Thick walled steel tube
(lance pipe)
Reinforced refractory (cladding)
Lance pipe
reinforcement

Figure 20 - Foseco lance /10/.

An essential feature of the design is the refractory and inner steel reinforcement:

- Steel pins are added to the refractory cladding composition. This improves rupture/tensile strength and thermal shock resistance. The steel pins used vary from 0.25 to 0.5 mm diamter and 12.5 to 40 mm in length.

- The inner steel tube is heavily reinforced to give extra rigidity.

- Sprays or barbed wire are welded to the steel tube to improve adhesion between the metalwork and the cladding.

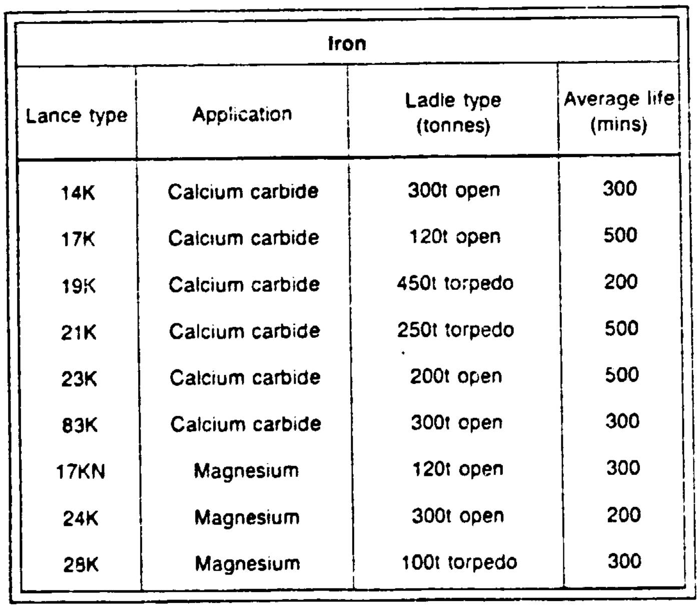
- Highest quality alumina refractory is used for the cladding material.

Iron desulphurization lances

Iron injection lances are used with magnesium, calcium carbide and lime in both torpedo and open ladles for desulphurization. The lance design varies with the injection reagent used; straight-through (vertical) outlet design lances are used for calcium carbide or lime and horizontal systems with one or more ports are used for magnesium.

Injection lance life depends on the operation conditions. The tables below show the average service life of Foseco hot metal desulphurizing lances.

Table 9 - Average service life of Foseco lances /11/.



Iron			
Lance type	Application	Ladle type (tonnes)	Average life (mins)
14K	Calcium carbide	300t open	300
17K	Calcium carbide	120t open	500
19K	Calcium carbide	450t torpedo	200
21K	Calcium carbide	250t torpedo	500
23K	Calcium carbide	200t open	500
83K	Calcium carbide	300t open	300
17KN	Magnesium	120t open	300
24K	Magnesium	300t open	200
28K	Magnesium	100t torpedo	300

Höganäs lance

The Höganäs lance is constructed from a refractory castable which has been specially developed for lance applications.

The castable is available in three qualities, has an Al_2O_3-content 81-96% and an operative temperature range of 1700-1800°C. For HM-treatment the quality with 81% Al_2O_3 is recommended.

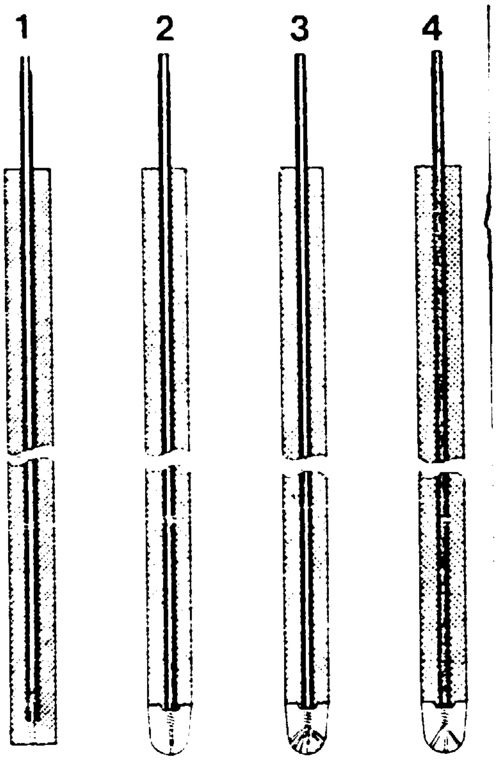
For injection, the Höganäs lance is available with a replaceable head and with one or several outlets.

The steel injection pipe and reinforcement is carefully integrated with the castable.

Radex lances

Injection lances from Radex are made of high quality refractory products with an Al_2O_3 content of about 90%. Monolitic lances can either be supplied as pre-fabricated pieces or made by the customer himself. In both cases, a steel pipe or a steel pipe combination reinforced, is lined with a refractory material.

Figure 21 shows various types of Radex injection lances.



1. Standard lining
2. Wear resistant head
3. Hedgehog head and directional porosity
4. Multiple aperture lance head

Figure 21 - Radex injection lances /12/.

IRSID injection lance

Joint work with the French Steel industry's IRSID research team has led to the development of a novel monolitic prestressed lance, see Figure 22. This lance can be used for powder injection in hot metal and steel and for argon stirring of steel. A special design for injection of unmixed or slightly diluted magnesium has been developed. The lance body is built around a strong central tube protected by a thick cylindrical aluminous refractory sheet, with an external diameter above 210 mm. The special injection technique uses two different circuits:

- a central conveyance circuit in which circulates only about 30% of the gas; in this way, the powder is conveyed at low speed.
- an annular circuit in which approximately 70% of the total gas flow circulates at a rate of 100-200 m/s around the central tube, acting as a thermal shield for the magnesium powder carried in the central tube.

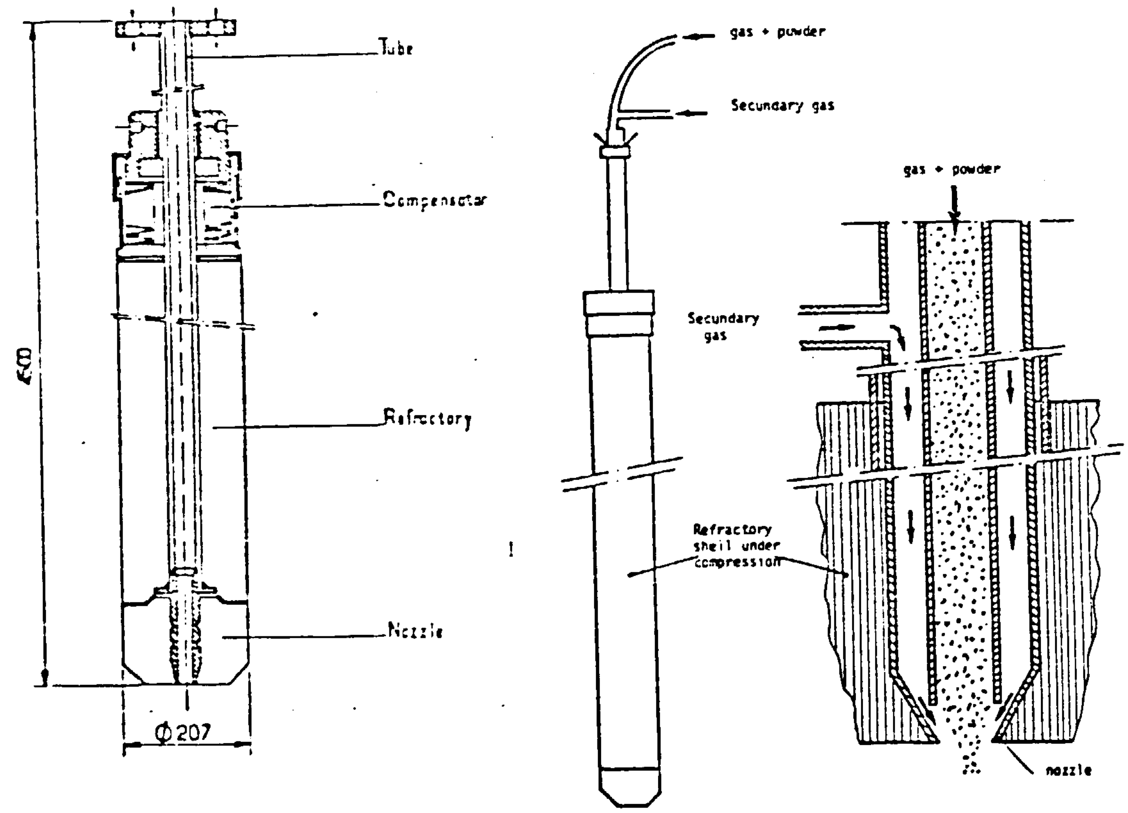

Tube
Compensator
Refractory
Nozzle
400
Φ207
gas + powder
Secundary gas
gas + powder
Secundary gas
Refractory shell under compression
nozzle

Figure 22 - IRSID injection lance /13/.

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Physical test methods for tar-bonded, tar-bonded tempered and fired tar-impregnated basic refractories

35th PRE Recommendation – 1977

Introduction

This document only describes the physical test methods for tar-bonded, tar-bonded tempered and fired tar impregnated basic refractories. For chemical analysis test methods, see PRE/R 33 'Chemical analysis of magnesite and dolomite products'.(1)

There is presently a choice between two methods for the preparation of coked test pieces. The final selection of the recommended method will be made following detailed comparative testing. This document will be revised when this work is completed.

This document contains a comprehensive list of tests. Not all of them may be required in order to characterize the material. One can choose some properties based on these test-methods, preferably not more than 3, which should then be subjected to a statistical control.

1. Object and field of application

Recommended test procedures are given for the examination of a range of basic refractories containing tar or pitch. These products are made of sintered dolomite, sintered magnesia or mixtures of these two materials and are manufactured in the form of tar-bonded, tar bonded and heat-treated, or tar-impregnated blocks or bricks. (The term tar also covers pitch.) The definition is as follows:

- *Tar bonded:*
  An unfired refractory shape which has been produced by pressing a mixture of graded aggregate and tar.
- *Tar-bonded, tempered:*
  A tar bonded shape which has been heated to a relatively low temperature (up to 800 °C) in order to remove volatiles from the tar and give an improved strength at low temperatures. The term 'tar-bonded tempered' is taken to include heat-treated, stoved and toughened materials.
- *Tar-impregnated:*
  A fired shape that subsequently has been completely impregnated by tar.

2. Sampling and preparation of test pieces

2.1 Sampling

The number of items (bricks) to be tested shall be determined in accordance with ISO/DIS 5022 (see PRE/R 7) or with another sampling method agreed between the parties concerned.

2.2 Preparation of test pieces

One, or if necessary, two adjacent sections are cut from the centre of the brick parallel to the hot face (fig. 1a). The sections should be the appropriate thickness for the test. With water sensitive materials cutting is dry and with all other materials wet. Fired, tar free dolomite may be cut wet if not possible by other means but should be immediately dried at 500 °C in a preheated furnace.

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(1) **PRE/R 33 does not deal with P_2O_5, ZrO_2 and B_2O_3**

The appropriate test pieces, required for the particular test described in the following test procedures, are cut or drilled from the core of the section i. e. 15 mm from the edge (as illustrated in fig. 1b).

2.2.1 *Procedure for dry drilling and cutting*

The drilling should be interrupted every 5 s. to blow out debris. During the entire drilling process compressed air may be introduced axially from above the interior of the drill. The dust derived from the drilling or cutting operations should be removed by suction.

2.2.2 *Procedure for drying tar-containing but not water sensitive specimens which have been prepared using water*

It is recommended that tar/pitch containing samples should be dried in a blast of warm air with free air flow to all surfaces in a manner such as not to affect the tar bond or impregnant.

3. Testing

3.1 Tests on specimens 'as supplied'

(i. e. in the original state)

3.1.1 *Bulk density*

3.1.1.1 *Determination of bulk density according to PRE/R 9*

A sample containing free lime must not remain wet longer than $^1/_2$ hour if water is used.

Drying procedure for tar containing samples is given in 2.2.2.

3.1.1.2 *Determination of bulk density by measuring and weighing*
the whole brick (the weighing shall be made to within 0,2%).
Lengths greater than 250 mm are determined with a steel tape measure furnished with a right-angled rigid hook (about 5 mm) and graduated in mm.

Dimensions below 250 mm are measured with calipers to an accuracy of 0.1 mm. The whole brick should be measured as follows: the length, width and thickness twice each; however width and thickness should be measured separately at the top and at the bottom of the brick (fig. 2). The calipers should be placed on the brick not further than 10 mm from the edge because of the possibility of tapering.

Since false results can be obtained should the brick be bowed, bricks to be used for the determination of bulk density must not bow by more than 2 mm over their whole length. For this purpose a gauge with 2 mm plungers at its ends is recommended.

3.1.1.3 *Determination of bulk density by mercury balance*
(According to PRE/R 19) note that for safety reasons a closed mercury volumeter is recommended;

3.1.2 *Apparent porosity* (Pa)

Apparent porosity is determined according to PRE/R 9. Liquid absorption is determined on brick fragments from the core of the brick (no cut surfaces). For precautions during the storage of freelime-containing fragments in water see section 3.1.1.1.

Organic solvents in which tar is soluble should not be used with tar containing test pieces. Where water is used the drying procedure is given in section 2.2.2.

3.1.3 *Cold crushing strength*

Cold crushing strength should be determined according to PRE/R 14. Cubic test pieces are also permissible with water sensitive materials, however, the geometry of the test pieces should be stated when quoting the results. Tar-bonded test pieces should be kept at (22 ± 2) °C until a constant temperature is attained in order to eliminate the influence of test temperature. The temperature at which the test is carried out should be reported if the recommended temperature cannot be adhered to for tar bonded materials. Test pieces containing free lime should be stored over a drying agent.

3.1.4 *Cold modulus of rupture*

Cold modulus of rupture tests should be carried out according to PRE/R 21. Precautions concerning testtemperature for tar bonded materials are to be observed as described in 3.1.3.

3.2 Determination of tar content and tests after the extraction of tar

3.2.1 *Soluble tar content*
Normally fragments from the core of the brick (or from the tempered surface layer of the brick – in which case this must be stated in the report), in an amount of at least 250 g, are crushed to approximately the original grain size, weighed and extracted with toluene or trichlorethylene(2). The extraction must be continued until the solvent liquid flows clear.

The crushed, and particularly the extracted, material must be protected from hydration, especially during the drying process.

The content of soluble tar is the difference in weight before and after the extraction.

With a Soxhlet type apparatus there is the danger that the very fine material passes through the filter. In such a case, centrifuging of the solvent is recommended.

3.2.2 *Insoluble tar content*
The sample remaining after tar extraction (3.2.1) is transferred to basins dried and weighed and then placed in a muffle furnace heated to 1000 °C for a period of 4 hours.

The samples should be allowed to cool and then reweighed. The insoluble tar shall be calculated from the difference in weight before and after ignition and the results expressed as a percentage of the original weight.

3.2.3 *Grain size distribution of extracted tar bonded material*
Fragments approximately 500 g in weight, taken from the core of the brick and having no cut surfaces are carefully broken into pieces, approximately 35 mm diameter, and then tar extracted using a dried weighed filter thimble (cf. section 3.2.1). The thimble is then emptied onto a sieve. After emptying, the thimble is dried and weighed again to determine the finer particles in it; this weight is then added to the weight of the particles of the sieve analysis. A correction is made for the insoluble tar content as determined in section 3.2.2. The sieves to be used are those specified in ISO 565.

Note: It is possible to check the grain size distribution of incoming bricks into a steelplant by this method but this test can only give an indication if there has been a significant change in grain size distribution of the product. It is impossible to identify the same particle size distribution as the producer of the brick used for its production by any method.

3.2.4 *Determination of bulk density of granular materials*
The bulk density of the granular material is carried out on grains $\leq$ 5,6 mm and $\geq$ 2 mm according to PRE/R 30 by either:

a) arrested water adsorption method.
b) mercury displacement method.

3.2.5 *Total tar content*
The total tar content can be determined in two ways:

a) summation of soluble and insoluble tar contents,
b) percentage weight change on heating a tar-containing sample to 1000 °C to constant weight as in section 3.4.

3.3 Tests after coking (reduting firing)

3.3.1 *Preparation of coked samples*
There is currently no agreed standard procedure for the preparation of coked samples, co-operative coking tests are currently in progresss in order to determine the method to be adopted in the future.

For 2 years there is a recommendation to use the following methods:

- ASTM C 831 – 76
- British coking test procedure (Refractories Journal, sept./oct., 1978).

Note: It is possible that during the preparation of coked samples that carbonation of the refractory oxides occurs and also that the iron compounds are reduced.

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(2) Trichlorethylene is to be used with caution because it is known to be a narcotic and addictive. (The results with toluene and trichlorethylene are not the same for some tar bonded products. Different values may be obtained with the two liquids. The liquid used should be stated in the report.)

3.3.2 *Weight loss during coking*

Weight loss during coking is the difference in the weight of the test pieces before and after carrying out the coking procedure specified in section 3.3.1. and is expressed as a percentage of the original weight.

$$\text{Weight loss on coking: } \frac{\text{Original Weight} - \text{Coked Weight}}{\text{Original Weight}} \times 100\,\%$$

3.3.3 *Cold modulus of rupture*

Specimens should be prepared according to section 4.3.1 and the report should contain a reference to the coking procedure adopted. The testing procedure should be carried out according to PRE/R 21.

3.3.4 *Cold crushing strength*

As specified in section 3.1.3. In this case it is not necessary to keep the temperature constant.

3.3.5 *Bulk density*

As in section 3.1.1.1.

3.3.6 *Apparent porosity*

As in section 3.1.2.

3.3.7 *Determination of the carbon content of coked bond*

The coked samples should be weighed and heated in a furnace of suitable size to 1000 °C to constant weight. Arrangements should be made to maintain an oxidising atmosphere e. g. by a stream of air through the furnace. The samples are cooled in the furnace and then transferred to a dessicator and afterwards reweighed. The heating rate of the sample is not critical providing that it has been ground. The heating rate detailed in section 3.4.1 should be used if the sample is a cut section on which further tests are to be made.

The carbon content is the difference in weight before and after ignition expressed as a percentage of the coked weight.

$$\text{Carbon content: } \frac{\text{Coked Weight} - \text{Carbon free Weight}}{\text{Coked Weight}} \times 100\,\%$$

Note: It may be necessary to correct for carbonation of refractory oxides and also the reoxidation of the iron compounds that were reduced during the coking procedure.

3.3.8 *Permeability to air*

The determination of permeability to air is carried out according to PRE/R 16.

3.3.9 *Procedure for the determination of hot modulus of rupture under controlled conditions of atmosphere*

(in discussion).

3.4 Tests after carbon removal (oxidizing firing).

3.4.1 *Tar or carbon removal*

The appropriate test-pieces required for the particular test described in the following test procedures should be heated in a furnace of suitable size to 1000 °C at 250 K/h. Arrangements should be made to maintain an oxidising atmosphere e. g. by a stream of air through the furnace. The temperature of 1000 °C should be maintained for 12 h after which the test pieces should be allowed to cool in the furnace before being placed in a dessicator.

When carbon free specimens are being prepared from the tar containing state for modulus of rupture determinations then a heating rate of 60 K/h is recommended.

3.4.2 *Loss-on-ignition during oxidising firing*

Loss-on-ignition is the difference in the weight of the test material before and after firing at 1000 °C. The amount of material to be tested; 3 test-pieces per item. Ground samples prepared for chemical analysis should not be used for the purpose of this test.

3.4.3 *True density*

The determination of true density is carried out according to PRE/R 8.

3.4.4 *Bulk density and apparent porosity*

The determination of bulk density and apparent porosity is carried out according to PRE/R 9.

3.4.5 *Permanent change in dimensions on heating*

The determination of permanent change in dimensions on heating the prepared samples is carried out according to PRE/R 19.

3.4.6 *Permeability to air*

The determination of permeability to air is carried out according to PRE/R 16.

3.4.7 *Other tests*

Once the tar has been completely removed from the sample (see section 3.4.1) then normal PRE test methods should be used. This is particulary applicable to impregnated, fired brick products.

Note: A hydration test for doloma products is now being considered.

Fig. 1
Plan of the brick

Fig. 1a
Cutting of the section

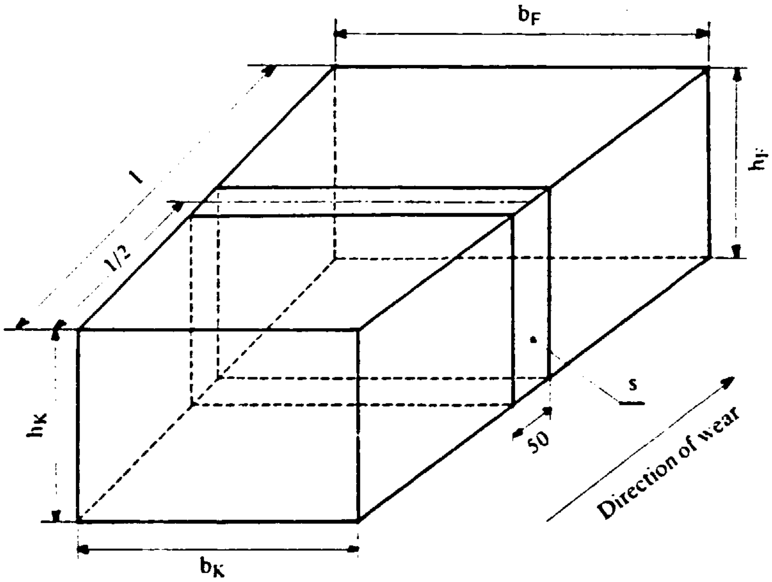
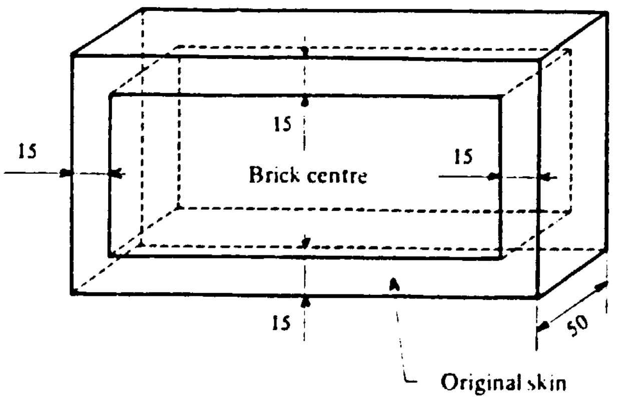
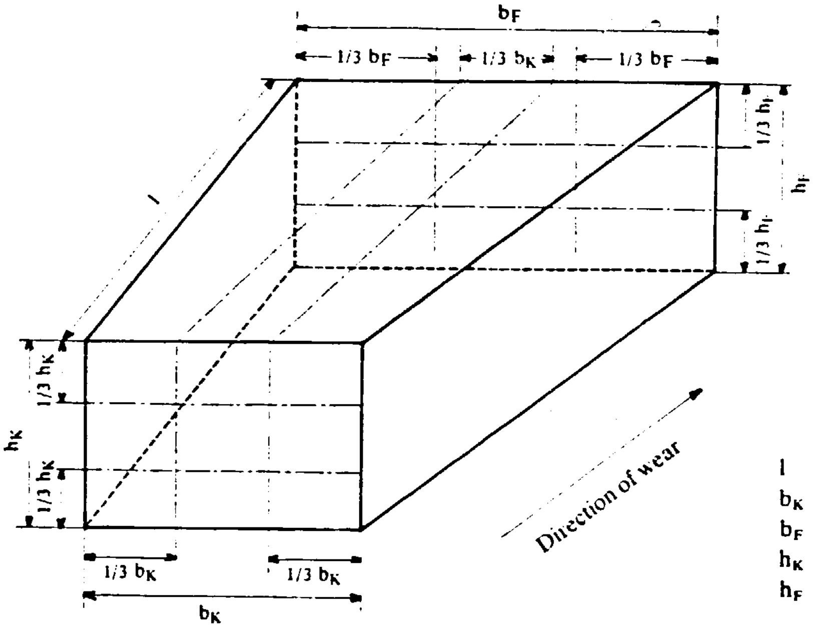

b_F
h_F
l
l/2
h_K
s
50
Direction of wear
b_K

Fig. 1b
Division of the section


15
15
Brick centre
15
15
50
Original skin

l = length
b_K = width on the inner face
b_F = width on the outer face
h_K = height on the inner face
h_F = height on the outer face

Fig. 2
Diagram with characteristic lines
for the measurement of the brick.


b_F
$1/3\ b_F$
$1/3\ b_K$
$1/3\ b_F$
$1/3\ h_F$
h_F
$1/3\ h_F$
l
$1/3\ h_K$
h_K
$1/3\ h_K$
$1/3\ b_K$
$1/3\ b_K$
b_K
Direction of wear

l = lenght
b_K = width on the inner face
b_F = width on the outer face
h_K = height of the inner face
h_F = height of the outer face

Determination of bulk density, apparent porosity and true porosity of dense shaped refractory products

9th PRE Recommendation – 1966 Revised 1976(1)

1. Scope and field of application

This recommendation specifies a method for the determination of the bulk density, the apparent porosity and the true porosity of dense shaped refractory products(2).

2. Definitions

For the purpose of this recommendation, the following definitions apply:

2.1 **bulk density:** The ratio of the mass of the dry material to its bulk volume. It may be expressed in grams per cubic centimetre or in kilograms per cubic metre.

2.2 **true density:** The ratio of the mass of the material to its true volume.

2.3 **true volume:** The volume of the solid material in a porous body.

2.4 **bulk volume:** The sum of the volumes of the solid material, the open pores and the closed pores. It is expressed by the external surface of the sample(3).

2.5 **apparent porosity:** The ratio of the volume of all the open pores to the bulk volume of the product. It is expressed as a percentage of the bulk volume.

2.6 **open pores:** Those pores that are penetrated by water or by the immersion liquid in the test described(4).

2.7 **closed pores:** Those pores that are not penetrated by water or by the immersion liquid in the test described.

2.8 **closed porosity:** The ratio between the total volume of the pores defined in 2.7 and the bulk volume of the test piece. It is expressed as a percentage of the bulk volume.

2.9 **true porosity:** The sum of the apparent porosity (2.5) and the closed porosity (2.8).

3. Principle

Determination of the dry mass of a test piece, then of its apparent mass when immersed in a liquid with which it has been impregnated under vacuum, then of its mass in air while still soaked with the liquid.

Determination of the bulk density, apparent porosity and true porosity by calculation.

4. Apparatus

Drying oven.

Balance with an accuracy of ± 0.05 g.

Hydrostatic balance with an accuracy of ± 0.05 g.

Evacuating equipment, capable of reducing the pressure to a value not greater than 25 mbar, and a means of measuring the pressure used.

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(1) This text is similar to ISO/DIS 5017.

(2) Refractory products with a true porosity less than 45%.

(3) The roughness of the surface limits the accuracy of definition of the bulk volume and, in consequence, of the bulk density. Also, the notion of bulk density becomes less precise when the volume of the sample diminishes below certain limits or when its texture (size of pores and grains) is too coarse.

(4) These pores, in principle, are all those that are connected with the atmosphere, either directly or via one another. Here again the roughness of the surface imposes a limit to the accuracy of the definition of the volume of the open pores.

5. Number and shape of test pieces

The number of items (bricks) to be tested shall be given by the sampling plan.

The number of test pieces to be tested per item (brick) shall be agreed between the parties concerned; it shall be given in the test report.

In cases where several bricks are tested, the same numbers of test pieces shall be taken from each brick to allow statistical evaluation.

Broken pieces, whole pieces (if they are small in size), or test pieces cut in the form of cubes or cylinders may be used. The most suitable bulk volume of a test piece is not below 50 cm^3.

As far as possible, the superficial 'skin' (approximately 3 mm in thickness), which might have different porosity, shall be removed.

Any test piece showing cracks caused by its preparation, the presence of which might falsify the determination of the bulk volume, shall also be eliminated.

The ratio of the longest to the shortest dimension of the test piece shall not exceed 2:1.

6. Procedure

6.1 Determination of the mass m_1 of the dry test piece

Dry the test piece at (110 ± 5) °C to constant mass, i. e. until two successive weighings made before and after at least 2 h in the drying oven do not differ by more than 0.1%.

Before each weighing, place the test piece in a desiccator until it has cooled to room temperature. The weighings shall be made to the nearest 0.05 g.

The mass determined is the mass of the dry test piece (m_1).

6.2 Soaking of test piece

Place the cooled and dried test piece in an airtight vessel. After sealing the vessel, evacuate it until a constant pressure of 25 mbar has been attained: this shall take at least 15 min. In order to make sure that all the air has been removed from the test piece, detach the vessel from the vacuum pump and use a manometer to check that the pressure does not rise again. After this, progressively introduce the immersion liquid in such a way that the test piece, after 3 min, is covered with about 20 mm of liquid.

This liquid may be cold distilled water for all materials that do not react with water⁽⁵⁾. For materials that are sensitive to contact with water, an organic liquid, such as paraffin, shall be used.

Maintain the reduced pressure for 30 min after the introduction of the liquid. After this, release the vacuum and open the vessel.

6.3 Determination of the apparent mass m_2 of the immersed test piece

Place the test piece, while still immersed, on a hydrostatic balance and weigh it while completely immersed. The immersed pan of the balance shall be suspended by a thin thread. In this way the apparent mass of the immersed test piece m_2 is obtained. The weighing shall be made to the nearest 0.05 g.

6.4 Determination of the mass m_3 of the soaked test piece

Remove the test piece from the liquid and sponge it rapidly with a damp sponge or damp cloth to remove droplets and the surface film of liquid.

Immediately weigh the test piece in air. Take care to ensure that evaporation of the immersion liquid does not lead to any appreciable loss in mass during the weighing operation. In this way the mass of the soaked test piece m_3 is obtained. The weighing shall be made to the nearest 0.05 g.

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(5) In this case, it is also possible to follow the procedure set out in the test method for shaped, insulating products, preferably carrying out the test on standard bricks.

6.5 Determination of the density of the immersion liquid

Determine the density ϱ of the liquid used in the operation at the temperature of the test. (For water, see the table.)

Table
Density of water as a function of temperature between 15 and 30 °C

Temperature, °C	Density, ϱ, g/cm^3
15	0.999 099
16	0.998 943
17	0.998 774
18	0.998 595
19	0.998 405
20	0.998 203
21	0.997 992
22	0.997 770
23	0.997 538
24	0.997 296
25	0.997 044
26	0.996 783
27	0.996 512
28	0.996 232
29	0.995 944
30	0.995 646

7. Expression of results

The bulk density ϱ_b, in grams per cubic centimetre, is given by the formula:

$$\varrho_b = \frac{m_1}{m_3 - m_2} \cdot \varrho \qquad [1]$$

The apparent porosity π_a, as a percentage, is given by the formula:

$$\pi_a = \frac{m_3 - m_1}{m_3 - m_2} \cdot 100 \qquad [2]$$

The true porosity π_t, as a percentage, is given by the formula:

$$\pi_t = \frac{\varrho_t - \varrho_b}{\varrho_t} \cdot 100 \qquad [3]$$

The closed porosity π_f, as a percentage, is given by the formula:

$$\pi_f = \pi_t - \pi_a \qquad [4]$$

In these formulae:

m_1 is the mass of the dry test piece, in grams;
m_2 is the apparent mass of the immersed test piece, in grams;
m_3 is the mass of the soaked test piece, in grams;
ϱ is the density of the immersion liquid, in grams per cubic centimetre;
ϱ_t is the true density of the product, in grams per cubic centimetre.

The bulk density shall be expressed in grams per cubic centimetre or in kilograms per cubic metre (by multiplying the result from equation [1] by 10^3). The calculation shall be made to three significant figures.

The calculations of porosity shall be made to the first decimal place.

8. Test report

The test report shall contain the following information:

- designation of the test materials;
- number of test pieces per item (brick);
- vacuum used;
- liquid used;
- individual values and the median value for each item (brick).

Note:
The individual values are used for calculation of the median. The median is used for further statistical work.

Determination of the cold crushing strength of dense shaped refractory products

14th PRE Recommendation – 1967[1]

1. Object

The present method has for its object the determination of the resistance to rupture under a compressive force of dense shaped refractory products at ambient temperature.

2. Definition

The cold crushing strength is the quotient of the maximum load F_{max} supported by the test-piece during the course of the test to the initial cross-section A_0 of the test-piece:-

$$\sigma = \frac{F_{max}}{A_0}$$

It is expressed in $N \cdot mm^{-2}$ (= $MN \cdot m^{-2}$ = MPa)
These units are expressed in term of the old ones as follows: $1\ N \cdot mm^{-2} = 10.19\ kgf \cdot cm^{-2}$.

3. Test-pieces

3.1 Shape

It is recommended that the test-pieces should have the shape of a cylinder 50 mm diameter and 50 mm high, cut from the pieces to be tested in such a way that, unless the shape of the brick makes it impossible, the plane faces obtained are at least 4 mm distant from the original faces of the piece.

In the exceptional cases of products of very coarse grain size (> 12 mm), a cylinder 70 mm diameter and 70 mm high may be used. Similarly, when the shape of the bricks makes it impossible to cut test-pieces of 50 mm, cylindrical test-pieces 35 mm diameter and 35 mm high shall be used.

3.2 Tolerance

In order to reduce the scatter of the results and to achieve the best reproducibility, the test-pieces must be prepared with the greatest care.

3.2.1 *The following tolerances shall be allowed:*
- on the diameter: ± 0.5 mm
- on the height: ± 0.5 mm
- on the perpendicularity of the axis of the test-piece relative to the end-faces: deviation < 0.5 mm

a) for tests carried out with cardboard bedding (see para.7)
- faces shall be plane and parallel to within a deviation < 0.2 mm

b) for tests carried out without bedding
- faces shall be plane and parallel to within a deviation < 0.1 mm.

3.2.2 *Conformity with these tolerances shall be checked in the following way:*

- carbon paper shall be used to check whether the end-faces are plane;
- parallelism of the end-faces shall be checked by four measurements of the height of the test-piece. The difference between any two measurements shall not exceed the tolerances set out above;
- the perpendicularity of the axis relative to the end-faces shall be checked by placing the test-piece upright on a plane slab and applying a set-square to any generatrix of the cylinder. The deviation between this generatrix and the arm of the set-square shall not exceed the tolerance set out above.

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(1) This text is under revision and the test is being studied by ISO.

4. Taking the samples

4.1 Number

The accuracy of the result depends on the number of test-pieces submitted to the test, because this property always exhibits a wide scatter. Statistical treatment of the results makes it possible to determine the confidence limit of the results depending on the number of specimens tested, and the standard deviation usual to fabrication.

In no case should the number of test-pieces be less than 5.

4.2 Direction

All the test-pieces shall be cut in the same direction, preferably with their axes parallel to the direction in which the pressure was applied during shaping, because the crushing strength is a vectorial property, often influenced by the direction of application of the stress. If the direction of pressing is not known, it is recommended that the permeability should be measured in three directions at right angles to one another on cubic test-pieces cut from the piece to be tested, the crushing strength then being determined in the direction corresponding to the lowest permeability.

In particular cases, another direction of cutting may be selected by agreement, defined on the basis of the conditions of service, but it is still stipulated that all the test-pieces shall be cut in the same direction.

4.3 Position

If the quality of a consignment is to be assessed correctly, it will be as well to take several bricks and several test-pieces from each, taken from different positions. As a general rule, however, the taking of samples is governed either by sampling standards or by special agreements.

5. Drying the test-pieces

The prepared test-pieces shall be carefully dried by placing them in a drying-oven at (110 ± 5) °C to constant weight. They are then cooled and kept away from moisture until the test is begun.

6. Testing equipment

The hydraulic or mechanical crushing-strength machine shall have a measuring device capable of measuring the stress exerted on the test-piece to within ± 2%. To this end, the measuring range of the machine shall be adjusted to the mean value of the test results in such a way that none of the results falls below $^1/_{10}$ of the maximum value of the measuring range employed.

The platens of the machine should be polished and their centre clearly marked. One of the platens should be mounted on a 'knuckle' to compensate for small deviations from parallelism that may exist between the test-piece and the platen.

The application of the load should be continous and progressive.

7. Carrying out the test

The test-piece is placed at the centre of the platens of the machine. The use of cardboard or metal bedding sheets is still under discussion by special committees. Until a definitive decision has been reached on this matter, it should be stated in the report what type bedding has been used. The compressive load is then gradually increased at a rate of $1 \pm 0.1\ \mathrm{N \cdot mm^{-2} \cdot s^{-1}}$ until the test-piece crushes.

The maximum load applied by the machine is indicated by a maximum indicator; this is the value used for the calculation of the results of the test.

8. Expression of the results

Each test is calculated by dividing the value of the maximum load indicated by the press, by the cross-section of the test-piece calculated from measurement of the original diameter to within 0.1 mm.

All the results obtained shall be given with an indication of the location of each test-piece, but the value that is to be taken shall be the mean value of these results.

If the test has been carried out on test-pieces having a shape differing from the standard, this shall be stated in the report. It shall also be stated whether the test has been carried out with or without bedding sheets and the direction in which the test-pieces were cut shall be indicated.

9. Reproducibility of the method

There have not been sufficient tests to give the standard deviation of this method. However, they have demonstrated the influenc of the *surface condition of the platens of the press and the degree of finish of the test-pieces*. They also permit it to be stated that th standard deviation of the method is above 2.5 $N \cdot mm^{-2}$ (average crushing strength of the product being tested > 70 $N \cdot mm^{-2}$).

Determination of modulus of rupture at ambient temperature of dense and insulating refractory products

21st. PRE Recommendation – 1973 Revised 1978(1)

1. Object and scope

This recommendation specifies a method for determining the modulus of rupture at ambient temperature of shaped and unshaped dense and insulating refractory products, under the action of a stress increasing at a constant rate.

2. Definition

The modulus of rupture is defined as the maximum force resisted by a parallelipipedal test-piece of given dimensions when placed under stress in a three point bending apparatus.

The modulus of rupture (σ_F) is calculated from an equation derived from Hooke's Law on elastic materials.(2) It is expressed as the ratio between the bending moment (M_{max}) at the point of rupture and the moment of resistance W.

$$\sigma_F = \frac{M_{max}}{W}$$

3. Principle

Subject the test-pieces(3) to a bend stress which increases uniformly to rupture.

4. Apparatus

The apparatus must include a means for applying the load fulfilling the following requirements (cf. diagram of principle): it will comprise two parallel supports and a central thrust column which is capable of applying a load at a constant rate. As it is possible to use different shapes of test-pieces, the various distances between supports, the different radii of curvature and the tolerances are given in Table 1. A means of recording or indicating the load at rupture with an accuracy of ± 2% must be provided.

5. Sampling – number and preparation of test-pieces

5.1 Sampling

Determine the number of specimens comprising the sample according to ISO/DIS 5022 (cf. PRE/R 7). The sampling of unshaped products and raw materials will be carried out according to a method in preparation.

5.2 Number of test-pieces

When the test is made on test-pieces taken from one specimen, the number of test-pieces must be the same for all the specimens making up the sample. This number, and the format of the test-pieces, must be agreed between the parties.

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(1) This revision takes account of all the most important decisions made in producing ISO/DIS 5014.

(2) Refractory products do not always exactly obey Hooke's Law.

(3) This method applies primarily to shaped products which have been fired once. If it is desired to test unfired or unshaped products, previous treatment may be necessary. (For unshaped materials see PRE/R 28).

5.3 Preparation of test-pieces

5.3.1 *Format*

Unless agreed otherwise the test-piece will comprise a complete brick of standard format 230 mm × 114 mm × 75(76) mm. Other formats may also be used – their sizes and tolerances are given in the table.

5.3.2 *Preparation*

Bricks of standard format are to be tested as received, and test-pieces prepared from unshaped materials. Where test-pieces are cut, take them so that the upper longitudinal face of the test-piece in the test position (face in compression) coincides with or is parallel to one of the original faces of the specimen (face perpendicular to the direction of pressing).(4) Cut preferably with a continuous bladed diamond saw.(5) Indicate the direction of pressing on the test-pieces.

5.3.3 *Drying*

Dry the test-pieces before testing at (110 ± 5) °C to constant weight.

5.4 Measurement

Measure the height and the width of the test-pieces in the middle to within ± 0.1 mm (these values are used to calculate the modulus of rupture).

6. Procedure

Place the test-piece on the lower support so that it rests symmetrically. If the test-piece is a brick of standard format place the face carrying the identifying marks under compression. If test-pieces cut from a specimen are being used, place in compression the face which corresponds to the original face of the brick where this has been preserved.

Apply the load vertically, in the direction of pressing of the brick if this is known, and at constant rate, to rupture of the test-piece. Measure the maximum load F_{max}.

Increase the bending stress at a rate of $0.15\ \mathrm{N \cdot mm^{-2} \cdot s^{-1}} \pm 10\%$ for dense products and at a rate of $0.05\ \mathrm{N \cdot mm^{-2} \cdot s^{-1}} \pm 10\%$ for insulating products. The actual load applied to each test-piece per unit time is calculated according to the formula given in section 7.

7. Calculation of modulus of rupture

The modulus of rupture is calculated from the formula

$$\sigma_F = \frac{3}{2} \times \frac{F_{max}}{b} \times \frac{L_s}{h^2} = \frac{M_{max}}{W}$$

in which

F_{max} = maximum force
Ls = distance between supports
b = breadth of test-piece
h = height of test-piece.

Express the result in $\mathrm{N \cdot mm^{-2}}$ (= $\mathrm{MN \cdot m^{-2}}$ = MPa). (Kgf · $\mathrm{cm^{-2}}$ with the ratio $1\ \mathrm{N \cdot mm^{-2}} = 10.19\ \mathrm{kgf \cdot cm^{-2}}$ may also be used).

8. Expression of results

8.1 Shaped products – bricks of standard format

The value obtained for 1 brick constitutes the test value.

8.2 Cut test-pieces and unshaped products

Give the individual values for each test-piece, and the mean per specimen, this latter value being the test value.

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(4) If it is not possible to preserve the firing skin on all the test-pieces taken from one specimen, eliminate it from all of them.

(5) When a toothed saw is used it often happens that the edges of the cut on the side where the saw emerged are damaged. It is therefore recommended that the saw penetrates the specimen on the face which will be under tension during the test.

9. Test report

Indicate in the test report:

- the designation of the brick (consumer, manufacturer, type, format etc.);
- number of test-pieces per specimen giving a test value;
- number of specimens;
- dimensions of test-pieces;
- position of test-piece(s) in the brick;
- if applicable, prevous treatment;
- the distance between supports;
- actual rate of increase in bend stress for each test-piece;
- the individual and mean values for each specimen;
- the place and date of the test.

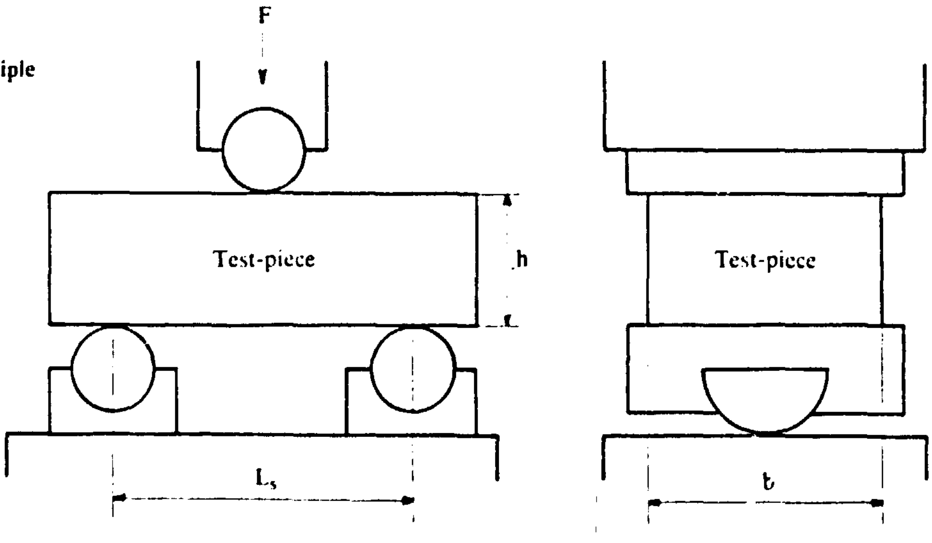
Format of test-pieces	**Tolerances for breadth b and height h**	**Tolerances for parallelism between the sides of a transverse section**	**Tolerances for parallelism between the longitudinal faces of the test-piece**	**Distance between supports L_s**	**Radius of curvature of support and thrust column(1)**
230×114×64 (76)				180 ± 1	15 ± 0.5
For unshaped materials 230×64×54 (cf. PRE/R 26) addition	± 0.5(2)	0.2(2)	0.3(2)	180 ± 1	15 ± 0.5
200×40×40	± 0.5	0.15	0.25	180 ± 1	5 ± 0.5
150×25×25	± 0.5	0.1	0.2	125 ± 1	5 ± 0.5

All dimensions are in mm.

(1) The length of the supports and thrust columns must be at least 5 mm greater than the breath of the test-pieces. The thrust column must be parallel to the supports and positioned in the centre of the distance between supports with an accuracy of ± 2 mm.

(2) Valid for the internal sides of the mould.

Diagram of principle



Determination of bulk density of granular materials

30th PRE Recommendation – 1977(1)

1. Object

The present recommendation describes the determination of bulk density of granular materials with grain size larger than 2 mm.

2. Definition

The bulk density ϱ_R of a material is the ratio of its mass to its volume inclusive of the volume of pores.

The bulk density is calculated from the following formula and reported in g/cm^3

$$\varrho_R = \frac{m}{V_R}$$

in which

m = mass of the dried material
V_R = volume of the material

3. Principle

The volume of a given mass of a granular material with grain sizes between 2 and 5.6 mm is measured by displacement of a liquid.

Two methods may be used for the determination of the bulk density of granular materials.

method 1: the mercury method
method 2: arrested water absorption method

Depending on the nature of the material to be tested the two methods may give different results. Therefore any value of the bulk density must be accompanied by an indication of the method used or to be used in any case of arbitration.

4. Sampling – number and preparation of test samples

4.1 Sampling

A recommendation is in preparation by ISO.

4.2. Preparation of test samples

The material to be tested shall consist of fractions or groups of fractions with grain sizes above 2 mm. Laboratory samples are produced by sieving (after preliminary comminution of the material above 5.6 mm if need be). Test results can be affected by the comminution technique and the equipment used.

Any dust or loose particles adhering should be removed before testing by washing or, with materials sensitive to moisture or humidity, by air blowing.

4.3. Number of test samples

At least three test samples should be taken from the laboratory sample and one determination of bulk density should be carried out on each test sample.

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(1) This document has been passed on to ISO/TC 33

4.4. Size of test samples

The size of test samples to be taken depends on the grain size and homogeneity of the material to be tested.

grain fraction (mm)		Size of test samples (g)	
		good homogeneity	poor homogeneity
2.0 to 5.6	method 1	100	200
	method 2	50	50

Tab. 1: recommended amount of material for a single test sample

5. Method 1: The mercury method

5.1 Apparatus

Balance to weigh to ± 0.1 g
Drying oven
Desiccator
Vacuum pycnometer: a vessel as shown in fig. 1 (conical ground glass joints according to ISO R 383) and a test arrangement as shown in fig. 2.

5.2 Procedure

5.2.1 *Determination of the weight (mass) m_p of a test sample*

Before weighing the test sample is dried at 110 ± 5 °C to constant weight and then cooled to room temperature in a desiccator. The accuracy of the weighing is 0.1 g.

5.2.2 *Determination of the volume V_R of a test sample*

The volume of the test sample is determined by the mercury displacement method with a vacuum below 30 mbar residual pressure, preferably with a residual pressure of 1.33 mbar (approximately 1 Torr) using the vacuum pycnometer (see fig. 1)

5.2.2.1 *Determination of weight m_L of empty vacuum pycnometer*
Clean and dry empty vacuum pycnometer and then weigh it to 0.1 g. This weighing is unnecessary if all the determinations are carried out at the same temperature.

5.2.2.2 *Determination of weight m_G of pycnometer filled with mercury*
Evacuate the vacuum pycnometer and fill it with mercury by suction until it emerges from the capillary (see fig. 2). Close the stopcocks 1 and 2 of the pycnometer in that order and disconnect the apparatus from the vacuum pump. Pour off the surplus mercury that has come out of the capillary and remove the mercury remaining in the suction capillary, up to stopcock 1, with a steel wire. Weigh the pycnometer filled with mercury to 0.1 g.

5.2.2.3 *Determination of weight m_T of the evacuated pycnometer containing test sample and filled with mercury*
Transfer test sample (weighed to 0.1 g) without losses into the pycnometer and fill this, under vacuum, with mercury as described in 5.2.2.2. This will give average pressure on the grain of about 265 mbar. Then weigh to 0.1 g. Thereupon, remove, under vacuum, the mercury from the vessel. Determine the amount of mercury still remaining in the test sample by weighing this sample after the adhering mercury has been removed and by finding the difference from the original weight of the test sample.

If the weight of mercury remaining in the test sample is over 5% of the original weight of the sample, state the amount, as a weight percentage, in the test report.

5.2.2.4 *Allowance for the density of the mercury*

When carrying out the determinations according to 5.2.2.2 and 5.2.2.3 changes in the density of mercury wit temperature shown in tab. 2 must be taken into consideration.

T in °C	ϱ in g/cm³	t in °C	ϱ in g/cm³
15	13.559	23	13.539
16	13.556	24	13.536
17	13.554	25	13.534
18	13.551	26	13.532
19	13.549	27	13.529
20	13.546	28	13.527
21	13.544	29	13.524
22	13.541	30	13.522

Tab. 2 Variation of density ϱ of mercury with temperature t

5.2.2.5 *Calculation of volume V_R of the test sample*

If the weighings were made according to sections 5.2.2.2 and 5.2.2.3 at a constant temperature and therefore with constant mercury density, use the following equation for calculating V_R:

$$V = \frac{m_G + m_p - M_T}{\varrho}$$

If the weighings were made at different temperatures and thus different mercury densities, use this equation for V_R:

$$V_R = \frac{m_G - m_L}{\varrho_1} \frac{m_T - m_L - m_p}{\varrho_2}$$

where:

m_G = weight of pycnometer filled with mercury only, in g
m_T = weight of evacuated pycnometer filled with test sample and mercury, in g
m_L = weight of empty pycnometer, in g
m_p = weight of test sample, in g
ϱ = density of mercury if calibration and measurement are carried out at same temperature
ϱ_1 = density of mercury when determining the filled weight m_G of the pycnometer containing mercury
ϱ_2 = density of mercury when determining the filled weight m_T of the pycnometer containing both test sample an mercury

6. Method 2: Arrested water absorption method:

6.1 Apparatus

Balance to weigh to ± 0.1 g
Drying oven
Desiccator
150 ml beaker
Flat weave cotton towel
Funnel, upper diameter approximately 100 mm
100 ml calibrated burette graduated in 0.2 ml (ISO/R 385)
Burette magnifier

6.2 Procedure

6.2.1 *Determination of the weight (mass) m_p of a test sample*

Before weighing the test sample is dried at (110 ± 5)°C to constant weight and then cooled at room temperature in desiccator. The accuracy of the weighing is 0.1 g.

6.2.2 *Determination of the volume V_R of a test sample*

The test sample is transferred to the 150 ml beaker and water at room temperature is added until the sample is covered. The burette should be freed from grease(2) and washed out immediately before use. It is filled with water to a level between the 20 ml and 25 ml marks and allowed to drain for 1 min before the initial reading is taken, by estimation, to one-tenth of a division (0.05 ml) with the aid of a magnifier. The funnel is then attached to the burette by means of a piece of plastic tubing.

The cotton towel is saturated with water and wrung out by hand as dry as possible before each determination. It is then folded to form a pad with four to six thicknesses of cloth.

When the test sample has been soaking for at least two minutes, a cover glass is placed over the beaker to retain the sample and the water is poured off as completedly as possible. The test sample is then transferred to the towel and blotted with the towel until the wet sheen on the grains has disappeared. The towel is then folded to facilitate pouring the test sample through the funnel into the burette. The final level is then read, by estimation, to 0.05 ml, with the aid of the magnifier.

The volume V_R of the test sample is given by the difference between the final and initial readings.

7. Calculation of the results

The bulk density ϱ_R is calculated from the following formula and reported in $g \cdot cm^{-3}$.

$$\varrho_R = \frac{m}{V_R}$$

in which

m = mass of the dried test sample
V_R = volume of the test sample

8. Repeatability of the methods

The repeatability of the two methods has been determined by means of non-porous control samples (e.g. glass spheres) of different bulk densities (2.0 to 4.0 $g \cdot cm^{-3}$). The bulk density of the control sample has been determined by PRE/R 8 without grinding.

Maximum deviation of the mean value from the nominal value	**Maximum difference between, highest and lowest value of multiple determinations**	
	for n = 2	**for n = 4**
± 0.01 $g \cdot cm^{-3}$	0.02 $g \cdot cm^{-3}$	0.03 $g \cdot cm^{-3}$

Tab. 3 Maximum difference between highest and lowest value of multiple determinations.

9. Test report

The test report should refer to this recommendation and should give the following data:

- method applied
- nature of sample
- grain size range and weight of the test samples
- bulk density ϱ_R in $g \cdot cm^{-3}$ to 0.01 $g \cdot cm^{-3}$
- individual values and arithmetic mean
- weight of mercury remaining in the test sample as a weight percentage (method 1 only)
- place and date of testing

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(2) The burette should be cleaned by filling it with a liquid made by adding 15 g of powdered sodium or potassium dichromate to 500 ml of concentrated sulphuric acid, and allowed to stand for a few hours, preferably overnight.

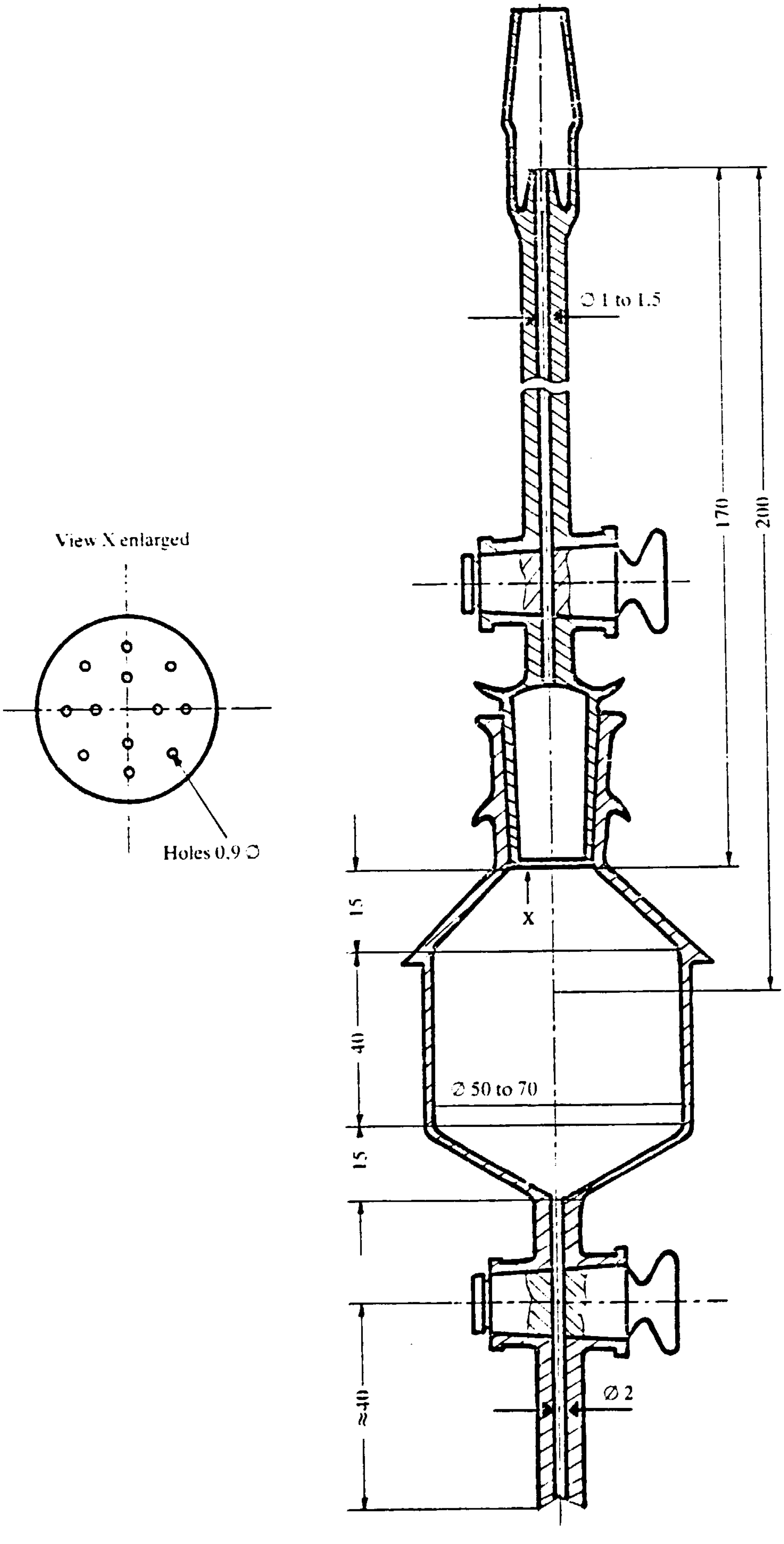
View X enlarged
Holes 0.9 ⌀
⌀ 1 to 1.5
170
200
15
X
15
40
⌀ 50 to 70
15
⌀ 2
≈40

Fig. 1
Vacuum pycnometer

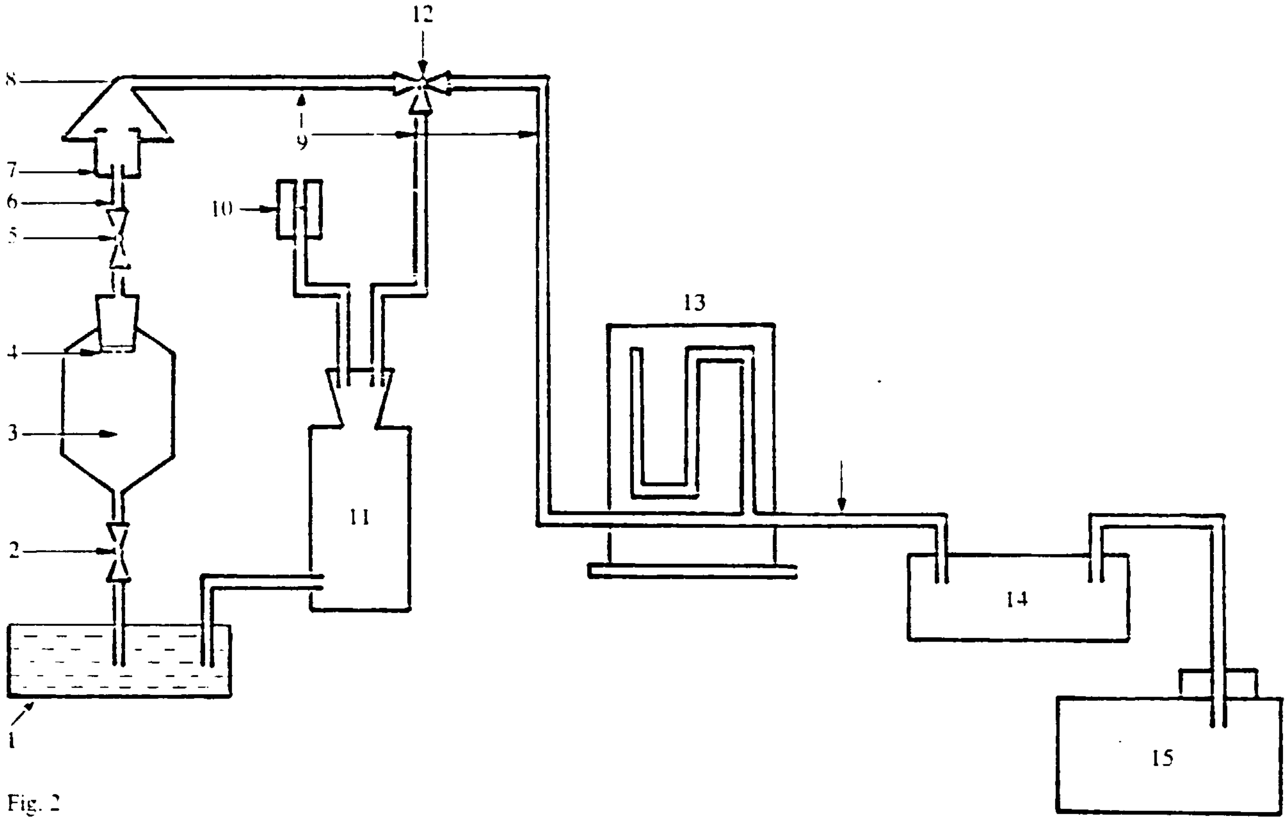

Fig. 2
Schematic representation of the test arrangement

1 Dish for Hg
2 Tap 1
3 Pycnometer lower part
4 Glass seal with 1 mm holes
5 Tap 2
6 Pycnometer upper part
7 Capillary and overflowtube
8 Pycnometer
9 Vacuum tubing
10 Hg extraction bush
11 Hg reservoir
12 3-way-tap
13 Vacuum
14 Woulfe's bottle
15 Vacuum pump

Determination of the permeability to gases of dense shaped refractory products

16th PRE Recommendation 1968 Revised 1972(1)

1. Object

The present method has for its object the measurement of the property exhibited by refractory materials of allowing a gas to pa through them when under a difference of pressure. It is valid for values of permeability greater than 0.05 nanoPerm whic correspond to a mean pore size of 0.1 μm. The determination is generally made by the passage of air.

2. Definition

The permeability is the factor μ in equation 1. which expresses the volume of gas passing through a material in a given time: th equation is deduced from the Hagen-Poiseuille law.

$$\frac{V}{t} = \mu \cdot \frac{1}{\eta} \cdot \frac{S}{L} \cdot (p_1 - p_2) \cdot \frac{(p_1 + p_2)}{2p} \tag{1}$$

where:

v = volume of gas at absolute pressure p passing through the material in time t
S = cross-section of test-piece presented to the passage of the gas
L = thickness of the material traversed
p_1 = absolute pressure where the gas enters
p_2 = absolute pressure where the gas leaves
η = dynamic viscosity of the gas at the temperature of the test
μ = permeability of the material

Note 1: p being the pressure under which the volume of gas flowing is measured: $p = p_1$ when operating under positive pressure and $p = p_2$ when operating under negative pressure.

Note 2: the correction factor $\frac{p_1 + p_2}{2p}$ is generally very close to 1 and may be neglected when operating with pressure difference $(p_1 - p_2)$ less than 100 mm water column. Equation(1) corresponds to Darcy's law.

3. Remarks

It should be noted that the permeability, unlike the density and the porosity, is a property that is directional and even vectorial. tha is to say, it varies according to the direction in which the measurement is made and even, in certain cases, according to the direction in which the gas is flowing.

The permeability is related to the distribution of the pores in the material and, because of this, is very sensitive to variations in texture; it is not directly related to the apparent porosity and it shows, within the same piece and even more so from one piece to another within the same batch, a much greater variation than does the porosity.

On the other hand, the determination itself is very accurate if care is taken to reduce to a minimum the experimental errors in determining the various factors in equation 1 by following the instructions set out in the present recommendation.

In order to judge the quality of a batch, or to know the variation of permeability as a function of the direction it is therefore essential to make quite a lot of measurements. As with all volumetric measurements it is essential to keep the apparatus away from air currents and sources of heat.

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(1) This document has been passed on to ISO/TC 33.

4. Units

Depending on which unit one favours, the different terms in the equation should be expressed in the following systems of units:

System of units	International System		cgs System		Technical System
Permeability	m^2	cm^2	Perm (cm^2)	Darcy	m^2
Dynamic Viscosity	$Pa \cdot s$	$Pa \cdot s$ (Pascal · second)	Poise ($dyn \cdot s \cdot cm^{-2}$)	Centipoise	$kp \cdot s \cdot m^{-2}$
Flow rate	$m^3 \cdot s^{-1}$	$cm^3 \cdot s^{-1}$	$cm^3 \cdot s^{-1}$	$cm^3 \cdot s^{-1}$	$m^3 \cdot s^{-1}$
Surface	m^2	cm^2	cm^2	cm^2	m^2
Thickness	m	cm	cm	cm	m
Pressure	Pa	Pa (Pascal)	$dyn \cdot cm^{-2}$	atm	$kp \cdot m^{-2}$

1 cm of water column = 98.7 Pa

To transpose the results obtained from one system to another, it should be noted that:

1 Perm = $1.013 \cdot 10^8$ Darcy = $10^{-4} m^2$
1 nanoPerm (nP) = 0.1013 Darcy = $1 \cdot 10^{-13} m^2$
1 Darcy = 8.87 nP
1 arbitrary English unit (BS 1902 – 1A–1966) = 190 nP

5. Test-pieces

A cylindrical test-piece 50 mm diameter and 50 mm high is used. The following tolerances are allowable:

on the diameter: ±0.5 mm
on the height: ±0.5 mm
on the perpendicularity of the axis of the test-piece to the faces
0.5 mm

In this case the determination may be carried out on the same test-pieces that will be used for subsequent determinations of cold crushing strength and refractoriness-under-load (see PRE/R 14 and PRE/R 4)

The test-pieces shall be cut in such a way that, unless this is not possible owing to the shape, the plane faces shall be at least 4 mm away from the natural faces of the brick.

The plane faces must be parallel to each other and perpendicular to the axis of the test-piece. The direction in which the test-pieces are cut relative to the direction of pressing of the brick shall be stated.

The faces shall be freed from dust formed during the cutting, by brushing under a jet of water if the cutting was done wet, or by a jet of compressed air if the cutting was done dry.

The test-pieces shall be dried by placing them in a drying-oven at 110 °C and drying to constant weight. They shall then be cooled away from moisture down to room temperature.

It is necessary that the test-pieces shall be close to the temperature of the air that will pass through them during the determination; this requires at least two hours of cooling to the temperature of the laboratory.

6. Apparatus

6.1 Test-piece holder

The test-piece holder should make it possible to ensure perfect sealing around the test-piece. The air-tightness is ensured by a rubber membrane that is inflated under a pressure of $0.2\ N \cdot mm^{-2}$ (fig. 1) to $0.4 N \cdot mm^{-2}$ depending on the properties of the rubber.

In special cases, the side faces can be coated with paraffin wax or picein, as long as it is ensured that the coating does not penetrate to the interior of the test-piece.

6.2 Measurement of the pressure

The difference in pressure between the two faces of the test-piece must be measured with a water manometer of the U-tube type. The usual experimental precautions for this type of measurement must be taken so that the error in the pressure determination does not exceed 1% (error in reading the height of the column, error in the density of the manometer liquid, error in the verticality of the manometer, meniscus error). The pressure should be determined close to one face of the test-piece in the vessel containing the test-piece holder; one should beware of the lower pressure readings when the pressure is determined in the connecting tubes.

6.3 Measurement of the flow

The flow of air or of gas through the test-piece can be measured with a sensitive rotameter[2] having an accuracy as good as 1%. It is recommended that the rotameter be calibrated periodically, and that only the middle section of its measuring scale be used. If a sufficiently senitive rotameter is not available, the measurement should be made by displacement of water in a graduated tube, taking the usual precautions for the measurement of the volume of water and using a chronometer for measuring the time of flow.

6.4 Measurement of the test-piece

In principle, the cross-section and the height of the test-piece should be known to within less than 5%, which necessitates the measurement of the height of the test-piece to within less than 0.5 mm and the measurement of the diameter to within less than 0.5 mm.

6.5 Supply of air under pressure or under suction

As the test must be carried out at constant pressure, this being chosen by the operator, either a reservoir of air at constant pressure must be available, or one must have equipment that will give air at constant pressure by the displacement of water.

In the latter case, it must be ensured that the tubing carrying the water is of sufficient diameter not to cause a loss of pressure that might alter the air pressure produced by the equipment, as a function of the rate of flow.

If a source of compressed air and a pressure-reducing device are used, it must be ensured that no error is introduced by the cooling of the air caused by the pressure-reduction.

6.6 Constructions and control of testing apparatus

Fig. 2 and 3 represent the testing apparatus under pressure or under suction. The piping, made of glass in preference to rubber, must be as short as possible in order that a very little pressure loss is produced in the apparatus compared with that produced by the test piece.

It is essential to ensure that the apparatus is air-tight by carrying out a blank test.

7. Carrying out the test

The test-piece is placed in the test-piece holder.

The air-tightness is checked by covering the cross-section of the test-piece with a waxed paper or with a plastic sheet: the flow should be zero.

It is essential that air flowing across the test-piece should have been previously dried.

It is advised that, for each test-piece, a minimum of three determinations be made at different pressures and to verify that the flow is in fact proportional to the pressure difference, because the basic equation [1] is only valid for laminar flow.

In principle, the permeabilities determined at three distinct pressure differences should not deviate amongst themselves by more than 5%.

---

(2) This type of flowmeter is calibrated for a given pressure of entry. If this pressure should be different, a correction must be applied.

3. Expression of the results

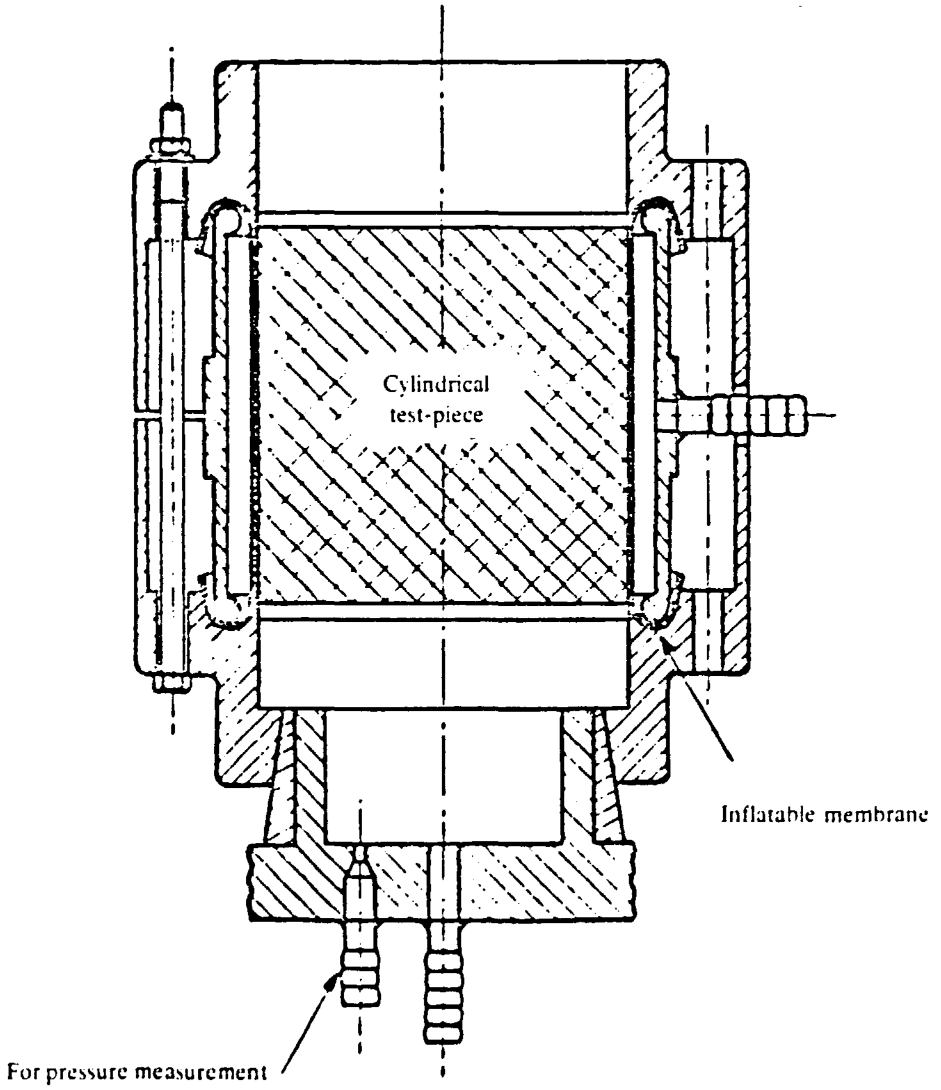
The permeability of the test-piece is calculated from equation [1] in which the values of the various factors determined during the course of the test are introduced, and the dynamic viscosity of the air is taken from the following table:

Temperature of the air in °C	**16**	**18**	**20**	**22**	**24**
Viscosity in μ · Pa · s	17.88	17.98	18.08	18.18	18.28

The results shall be given to 2 significant figures.

The report shall indicate the conditions of the test (description of test-piece, direction in which it was cut relative to the direction of pressing of the brick, pressure or suction, temperature).

Fig. 1


Cylindrical test-piece
Inflatable membrane
For pressure measurement

Determination of the true density of raw materials and refractory products

8th PRE Recommendation – 1966 Revised 1978[1]

1. Object and Scope

1.1 This recommendation specifies a method for determining the true density of raw materials and refractory products.

1.2 Both unfired refractory products and basic products may be fired beforehand, under conditions to be agreed between the parties concerned.

2. References

ISO 565 – Test sieves: wire gauze and perforated sheet – nominal mesh sizes.
ISO/R 836 – Vocabulary for the refractory materials industry.
ISO/DIS 5022 – Refractory products – sampling of shaped refractory products (cf. PRE/R7).

3. Definition

True Density: Ratio of the weight of dry material to its true volume V, expressed in kg/m³ (SI unit) or in g/cm³, using the formula

$$\varrho = \frac{m}{V}$$

True volume: Volume of solid material in a porous body.

4. Principle

Determination of the true density by measuring the dry weight and true volume of the test sample after it has been ground to a fineness where as far as possible no closed pores remain.

Determination of the true volume of ground materials, using a pycnometer and a liquid of known density, the temperature of the liquid being controlled or carefully measured.

5. Apparatus

5.1 It is recommended that a pycnometer of 25–50 or 100 ml capacity, fitted with a ground stopper having a capillary, be used.

5.2 Use a balance with an accuracy of ± 0.1 mg.

5.3 Use an air pump which will reduce the pressure to ≤ 25 mbar ($2500\ N/m^2 = 2500$ Pa). Provide a means of measuring the pressure.

5.4 Use a thermostatically controlled bath capable of maintaining a temperature 2 to 5 K above ambient, within ± 0.2 K.[2]

---

(1) This revision takes account of all the most important decisions taken in relation to the preparation of ISO/DIS 5018.

(2) This degree of accuracy in temperature control is necessary as the method is very sensitive to temperature variations. Because of differences between the coefficients of expansion of the pycnometer and the liquid significant errors may arise if the temperature varies.

6. Sampling – number and preparation of test-samples

6.1 Sampling

Determine the number of specimens according to ISO 5022 (cf. PRE/R 7) for shaped and unshaped fired products. The number and mass of the samples for unshaped unfired products and raw materials will be defined in a document in preparation.

6.2 Number of test samples

Determine by agreement between the parties the number of test samples. This number determines the mass of the laboratory-sample.

6.3 Preparation of test samples

6.3.1 *Grinding*

The test-sample shall be ground so as to pass completely through a sieve with a nominal 63 µm mesh size (cf. ISO 565).

Take care that the grinding process does not introduce any foreign material or water into the sample.

6.3.2 *Drying*

Before testing dry the laboratory-sample at (110 ± 5) °C to constant weight (two weighings two hours apart must not show any change in weight greater than 0.1 %). Before each weighing, place the laboratory-sample in a dessicator till it reaches ambient temperature.

Take care to avoid any hydration during preparation of basic refractory materials.

7. Method

7.1 Determination of the initial weight of the test-sample (P_1).

7.1.1 *Clean the pycnometer* and ensure that its exterior is completely dry. It is recommended that it be handled with leather fingers. Let it cool to a temperature near to ambient.

7.1.2 *Weigh the empty pycnometer*, clean and complete with its stopper, to within 0.0002 g.

7.1.3 *A quantity of the material* is then introduced into the pycnometer such that it fills approximately $^1/_3$ of its volume. When the pycnometer and its contents have been brought back to ambient temperature they are weighed to within 0.0002 g. The difference the two weighings represents the initial weight of the test sample (P_1).

Remark: If the material is difficult to wet with the liquid, and where a different method must be used, refer to Appendix A.

7.2 Determination of the weight of the pycnometer containing the test sample and the test liquid (P_2).

7.2.1 *Add to the pycnometer* (weighed according to 7.1.3) a quantity of boiled de-aired water or any other liquid of known density, so that the pycnometer is filled to $^1/_2$ or $^2/_3$ of its capacity. Place it in a desiccator and leave in a vacuum whose residual pressure does not exceed 25 mbar (2500 N/m^2 = 2500 Pa), until no more air bubbles are seen to rise. To ensure complete wetting the pycnometer may be shaken by means of a device placed in the dessicator or by any other method. When using a liquid other than water care must be taken that it does not boil at the pressure used.

7.2.2 *Fill the pycnometer* almost completely with the water or other chosen liquid, and allow it to settle until the supernatent liquid is only slightly cloudy (one night is usually sufficient).

7.2.3 *Fill the pycnometer* carefully, put in the glass stopper and carefully eliminate the liquid that exudes. Put the pycnometer into the thermostatically controlled bath and raise its temperature to between 2 and 5 K above ambient temperature (this temperature is the temperature of the test). Keep this temperature constant to ± 0.2 K.

7.2.4 *As the temperature approaches* the test temperature a little liquid escapes through the capillary in the stopper. Carefully remove this by absorbing it with a filter paper. The pycnometer has reached ambient temperature when the liquid ceases to escape through the capillary tube.

Remove the pycnometer from the thermostat, taking care that the heat of the hand does not reheat the pycnometer and cause supplementary loss of liquid (such reheating may be avoided by plunging the completely filled pycnometer into cold water for serveral seconds). Carefully wipe and dry the outside of the pycnometer and then weigh to within 0.0002 g. (weight P_2).

7.3 Determination of the weight of the filled pycnometer.

7.3.1 *Empty and clean* the pycnometer. Fill it almost full with water or the test liquid.

7.3.2 *Repeat the operations* described in 7.2.3 and 7.2.4 to determine accurately the weight of the pycnometer filled with th test liquid (weight P_3).

8. Expression of results

8.1 Calculate the true density ρ from the expression

$$\rho = \frac{P_1}{P_3 + P_1 - P_2} \cdot d$$

where:
d = density of the test liquid at the temperature of the thermostat (in the case of water, refer to the table).
P_1, P_2, P_3 = weights determined according to paragraph 7.

8.2 Express the true density in kg · m^{-3} or g · cm^{-3}. The values must be calculated to three decimal phases.

8.3 Give the individual values and the mean value for each laboratory sample, the latter being the test-value.

9. Test Report

Indicate in the report:
- the designation of the material;
- the number of items tested;
- the weight of each laboratory sample;
- if applicable, the number of test samples per laboratory sample;
- the weight of each test sample;
- heat treatment, if applicable;
- the pressure;
- the liquid used;
- the test temperature;
- the individual and mean values of the true density for each laboratory sample;
- the place and date of the test

10. Reproducibility of the method

For silica products the reproducibility of the pycnometer method given as a standard deviation is equal to 0.004 g.cm^{-3}.

Table:
Density of water as a function of temperature between 15 and 30 °C

Temperature (°C)	Density (g · cm^{-3})
15	0.999 099
16	0.998 943
17	0.998 774
18	0.998 595
19	0.998 405
20	0.998 203
21	0.997 992
22	0.997 770
23	0.997 538
24	0.997 296
25	0.997 044
26	0.996 783
27	0.996 512
28	0.996 232
29	0.995 944
30	0.995 646

Appendix A

Method for materials difficult to wet.

A1 – The process described in 7.2 may be replaced by this method if the material is difficult to wet and if it will not go into suspension satisfactorily.

A2 – Pour into the dry pycnometer a quantity of boiled de-aired water or any other liquid of known density to not more than $^1/_4$ of the capacity of the pycnometer. Weight the pycnometer and the liquid to within 0.0002 g.

A3 – Introduce into the pycnometer a quantity of dried test sample equivalent to $^1/_3$ of the volume of the pycnometer. Weigh the pycnometer again to within 0.0002 g.

A4 – The difference between the two weights represents the initial weight of the test sample. P_1.

Determination of the permanent change in dimensions under the action of heat of dense shaped refractory products

19th PRE Recommendation –1972 Revision 1978(1)

1. Object and field of application

The present recommendation specifies a method for determining the permanent change in dimensions of dense shaped refract products on heating to a predetermined temperature which is maintained for a specific period of time.

2. Definition

Permanent change in dimensions: The expansion or contraction remaining after cooling of a refractory product heated for a certa time at a given temperature. It is expressed, as a percentage, preferably by the ratio between the change ΔL of the length of the te piece and the original value L of this length (i.e. 100ΔL/L). It may also be expressed as the ratio of the change in volume ΔV to tl original volume (i.e. 100ΔV/V).

3. Principle

Cutting, from the sample to be tested, test-pieces in the form of cylinders or prisms of square cross-section and measurement of tl linear dimensions and if need be of their volume. Heating the test-pieces at a prescribed rate in a furnace having an oxidizi atmosphere, to a predetermined temperature, and maintaining this temperature for a specified period. (With a differe atmosphere different results may be obtained).

After cooling the test-pieces to the ambient temperature, re-determination of the linear dimensions and if necessary volume an calculation of the permanent change in dimensions.

4. Apparatus

4.1 Furnace

It is recommended that an electric furnace be used for these tests. However, tests in a gas-fired furnace are accepted provide that the atmosphere in the furnace is continuously oxidizing and that it has no reducing action on the test-pieces.

If an oxidizing atmosphere is not suitable for the test (for example, with tar-bonded bricks), the nature of the atmosphere is t be agreed between the parties.

The furnace must be such as to allow the test to be carried out in accordance with the method laid down in 6.2.

4.2 Thermocouples and recorder

4.3 Device for measuring the dimensions

Dial gauge comparator, or micrometer, mounted on a carrier which has a square steel baseplate conforming to fig. 1.

The accuracy of the measuring equipment must be 0.01 mm.

A diagonal should be marked on one corner of the plate to assist in locating rectangular test-pieces symmetrically on the studs

Calibration can be effected by means of a steel cylinder, 50 mm in diameter and 55 to 65 mm long, this length being accuratel known, placed vertically on the studs.

It shall be possible to rotate the test-piece so that its length can be measured at the other three corresponding positions.

---

(1) This revision takes account of all the most important decisions taken in relation to the revision of ISO 2478.

4.4 Devices for measuring the volume

A closed mercury volumenometer or a hydrostatic balance may be used, following the normal method for measuring the apparent volume of dense refractories (cf PRE/R 9).

5. Sampling – number and preparation of test pieces

5.1 Sampling

Determine the number of items constituting the sample according to ISO/DIS 5022 (cf PRE/R 7).

5.2 Number of test-pieces

The number of test pieces taken per specimen (individual) and the dirction of cut within the specimen must be agreed between the parties concerned. It should be indicated on the test pieces. The number of test pieces taken must be the same for all the specimens comprising the saple.

5.3 Preparation of test-pieces.

5.3.1 *Format*

The test pieces shall be in the form[2] of:
- either prisms of square section 50 mm × 50 mm × 60 mm ±1 mm
- or cylinders 50 mm in diameter and 60 ±1 mm high.

The 50 × 50 mm faces, or the ends of the cylinder shall be ground plane and parallel before the determination of the permanent linear changes.

5.3.2 *Drying*

Before testing, the test pieces shall be dried to constant weight at (110 ±5) °C.

6. Procedure

6.1 Measurement of the test-piece

6.1.1 *For permanent linear change*

Place each test-piece on the carrier. If the test-piece is a prism, align one corner with the diagonal mark on the carrier and mark this corner so that the piece can be placed in the same position for measurement after heating. If the test-piece is cylindrical, mark it near the diagonal mark.

Measure the length of the test-piece by means of the dial gauge comparator or micrometer at four positions, located on the diagonals of a prismatic test-piece at a distance of 15 to 20 mm from each corner, or on two diameters at right angles and 10 to 15 mm from the periphery on a cylindrical test-piece.

Draw a ring round each measuring point with refractory paint.

6.1.2 *For permanent volume change*

Determine the volume of each test-piece by hydrostatic weighing, by a closed mercury volumenometer or by measurement and calculation.

---

(2) If it is not possible to cut these shapes from the pieces to be tested, smaller shapes are to be agreed between the parties concerned.

6.2 Heating

6.2.1 *Disposition of the test-pieces*

Place the test-pieces vertically in the furnace.

Furthermore it is recommended that the test pieces be:
- placed on supports of the same material as themselves, of a thickness of 30–65 mm, themselves laid flat on the edges of two triangular prisms 20–50 mm high and 80 mm apart;
- 20 mm apart from each other to allow free circulation of the hot gases;
- 70 mm away from the furnace walls;
- protected from direct radiation from the heating elements in an electric furnace or the burners in a gas furnace.

To comply with the requirements of 4.1 make provision for sampling the atmosphere in the vicinity of the test-pieces at any time during the test and for the determination of the oxygen content of the furnace gases.

6.2.2 *Measurement of the temperature and temperature distribution*
Measure the temperature by means of at least three thermocouples placed so as to record the temperature distribution over the limits of the space containing the test-pieces and not touching either the furnace walls or the heating elements, or being protected from contact with flames; use a temperature-recorder so that a record of the temperature control is preserved. The use of a potentiometric recorder is recommended.

During the soak the temperature difference between any two thermocouples shall not exceed 10 K and the mean of the three readings shall be taken as the test temperature.

6.2.3 *Temperature of the test*

The test shall be carried out at a temperature at least equal to 800 °C or exceeding that temperature by a multiple of 50 K and agreed between the parties concerned.

6.2.4 *Heating schedule*

For test temperatures of 1250 °C or below:

– from ambient temperature to a temperature 50 K below the test temperature	5 – 10 K/min
– the remaining 50 K	1 – 2 K/min

For test temperature above 1250 °C:

– from ambient temperature to 1200 °C	5 – 10 K/min
– from 1200 °C to a temperature 50 K lower than the test temperature	2 – 5 K/min
– the remaining 50 K	1 – 2 K/min

Maintain the temperature within ± 10 K around the test temperature for the specified period, and then allow the furnace to cool at its normal rate till the following day, the specimens being left to cool in the furnace.

6.2.5 *Period at the test temperature*

The specified period at the test temperature is normally 5 h; however, when adequate information is not obtained thereby, a period of 12 or 24 h may be chosen.

6.3 Measurement of the test-pieces after the test

6.3.1 *For permanent linear change*

Measure the length of the test-pieces, after cooling to ambient temperature at each of the four points defined in 6.1.1 and using the method laid down in the same paragraph.

Do not remove blisters or accretions produced during the heating, but if any of the measurements at a marked point is affected by the presence of a blister or accretion which is not typical of the surface after the heating, the measurement made at that point shall not be included in the mean value. Similarly, if necessary, the test-piece shall be rotated to avoid contact between such a blister or accretion and any of the three supports of the measuring device.

6.3.2 *For permanent volume change*

Measure the volume of the test-pieces, after cooling, by the method previously laid down.

7. Expression of the results

7.1 Permanent linear change

Calculate the linear change at each measuring point as a percentage of the original length.

Indicate, for each test-piece, the individual values so calculated, and also the corresponding mean; however, if the changes in length of one test-piece are not all of the same sign, the mean for that test-piece shall not be given.

7.2 Permanent volume change

Calculate the change in volume of each test-piece as a percentage of the original volume.

8. Test report

Indicate in the test report:
- the designation of the material under test.
- the number of specimens tested.
- the number of test pieces per specimen.
- their dimensions and location within the specimen.
- the direction of cutting of the test-pieces.
- the type of furnace used.
- if necessary the oxygen content of the furnace atmosphere or the nature of this atmosphere.
- the heating rate.
- the test temperature.
- the duration of the soak
- the appearance of the test pieces after heating.
- the individual and mean values of permanent linear change for each test-piece, and if applicable the median value per specimen. (and if necessary the permanent volume change).
- the place and date of the test.

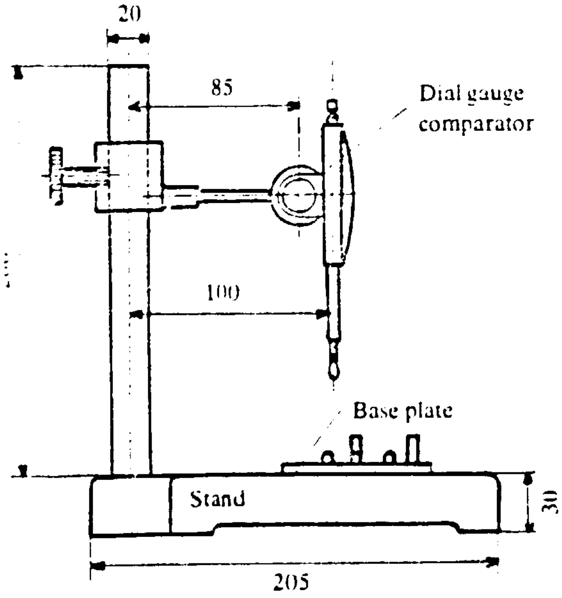


Fig. 1
Diagram of complete apparatus

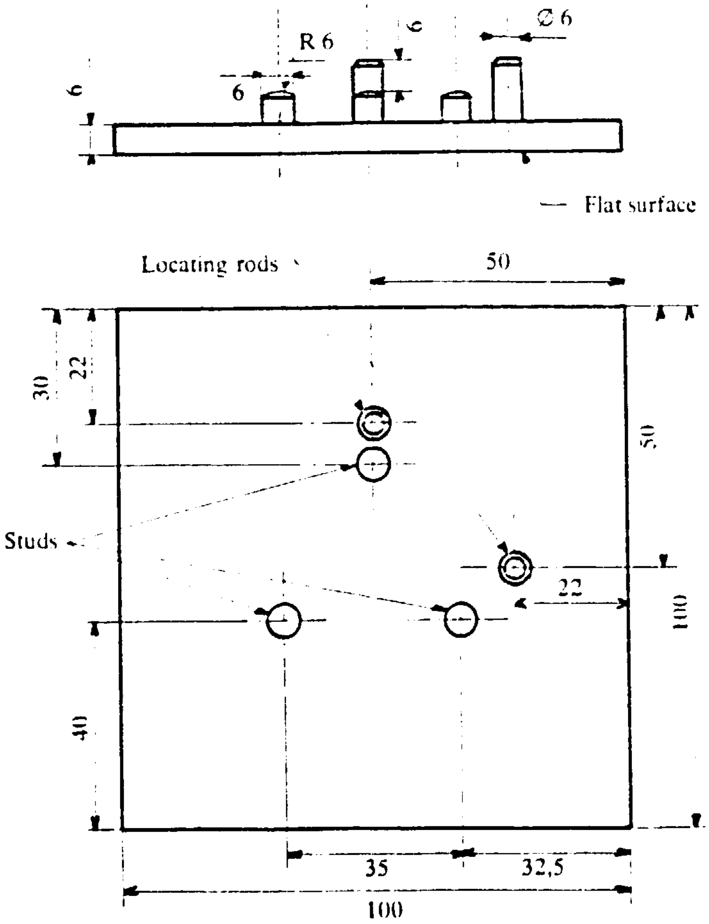


Fig. 2
Test-piece support

Dimensions in mm

MEFOS' rotary slag test

1. Lining of furnace

The test materials, which most conveniently are standard shaped bricks (230 x 114 x 76 mm), are sawn according to Figure 1. Not counting the sidewalls there is a need for 24 bricks (4 x 6) for each test. The test material should be of the same refractory type to avoid a mutual influence. For back lining it is suitable to use a castable. Jointing material is not necessary. Before lining the furnace the thickness of the twelve bricks (B1-B6, C1-C6) in the centre should be carefully measured.

2. Slag preparation

The test slag composition is chosen depending on process and actual slag in service. However, it is convenient to make the slag more aggressive than the actual slag in service to speed up the rate of wear. It is preferable to make a synthetic slag to make comparisons with other tests possible.

3. Temperature measurements

The temperature is followed by an optical pyrometer during the heating up. During the test the slag temperature is measured with a dipping pyrometer.

4. Test procedure

The furnace is heated with a propane-oxygen burner to the test temperature according to a desired temperature program (usually 3 h). It is recommended to add coalpowder during the heating of carbonaceous linings.

When the temperature is equalized (about 0.5 h) the slag is fed into the furnace through the side-wall opposite the burner. The slag feeding continues for at least 4 h, 1 kg slag every 10 minutes. The temperature is measured directly before each slag addition. The rotation speed, 4 rpm, is kept constant during the whole test.

When the test is over the furnace is tilted to tap off all the remaining slag. The furnace is then cooled during the night whereupon the bricks are pulled out to be measured.

5. Evaluation of test

Only the bricks in the centre are being used for the evaluation since the other ones have been exposed to random effects. The appearance of the attacked surface is noted after which the bricks are halved to measure the wear of the bricks in the region of the greatest wear. Crack formations and infiltration are also noted.

The test report should include the following:
- the different brick qualities
- used test slag
- temperature program for heating up
- test time
- average test temperature
- average wear for each brick quality
- average slag infiltration for each brick quality
- appearance of surface and crack formation
- date and place of testing

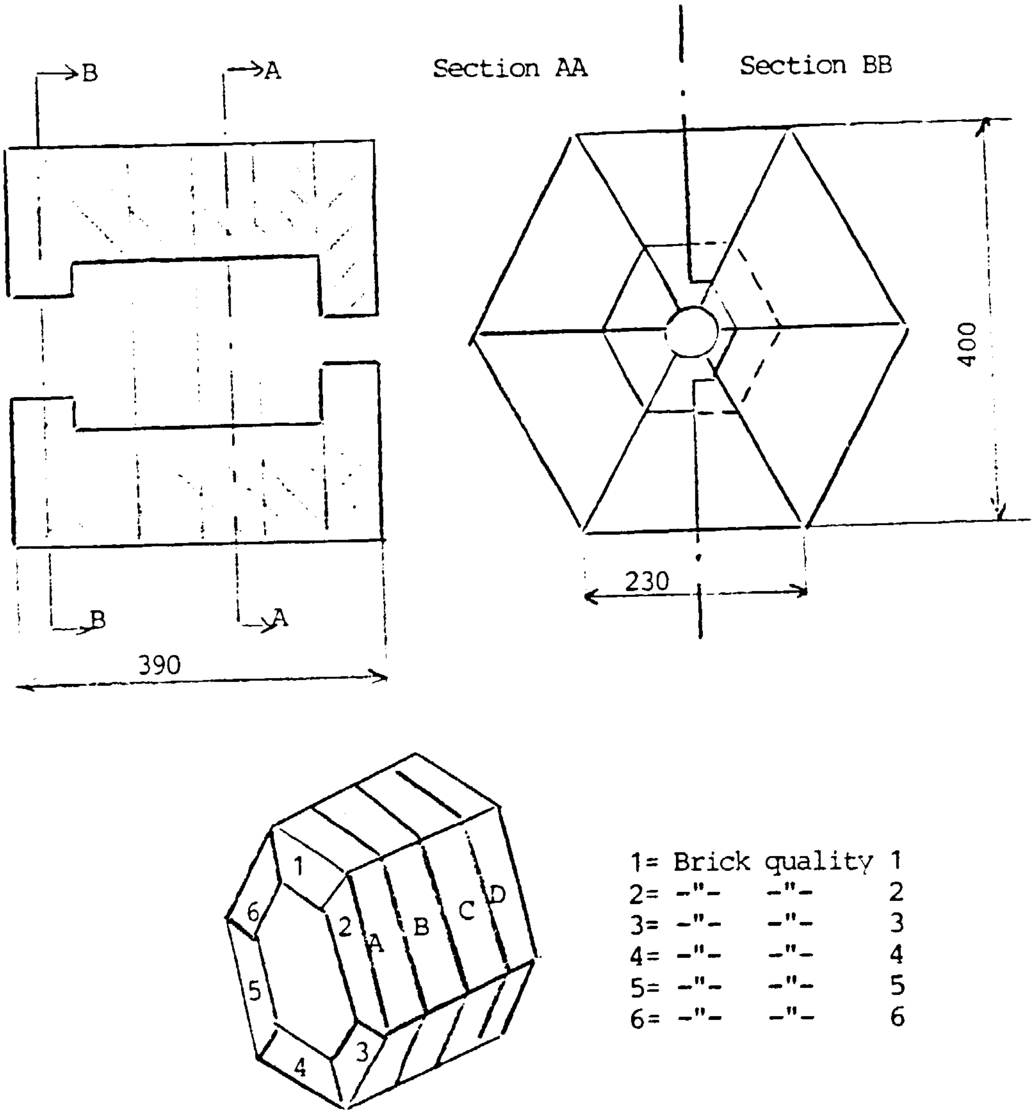

B
A
Section AA
Section BB
400
230
B
A
390
1
6
2
A
B
C
D
5
4
3
1= Brick quality 1
2= -"- -"- 2
3= -"- -"- 3
4= -"- -"- 4
5= -"- -"- 5
6= -"- -"- 6

Figure 1 - Furnace construction and lining.

Appendix 7

MEFOS
METALLURGISKA
FORSKNINGSSTATIONEN

Forskningsuppgift	Konto	Datum	Reg nr
UNIDO/INDIEN	4446	1985-02-27	PM1985/012/BD Bodil Dahlberg

Subject: DP/IND/81/036 - Design Development of Concurrent Top and Bottom Blown Converter Steel Making - Contract No. 84/66

COMMENTS REGARDING CLARIFICATION OF REFRACTORY PRACTICES PERTAINING TO COMBINED BLOWING PROCESS.

1 Stability of bottom brickwork for curved bottom vis-à-vis flat bottom

The change-over from conventional LD-process to CB-process has, in most converters, resulted in increased bottom wear. The area close to the purging element and the junction between bottom and barrel will be exposed to the highest wear rate.

With the flat bottom we foresee a possible risk of the bottom lining falling out if any bricks, for some reason, become too worn.

We think the proposal from Radex regarding curved bottom has one weakness; the area of ramming material in the junction between bottom and barrel is too big. Judging by experience with Swedish converters, we suggest that it is better to cut some bricks in order to increase the area of bricks in the bottom and minimize the use of ramming material.

2 Location of permeable elements

The main reason for the proposed location of the purging elements is that during tapping and deslaggning the elements will be above the bath level. From the refractory view point this is preferable as far as the purging element and the surrounding area are concerned. However, the area that is to be exposed to a high wear rate, that part of the junction between barrel and bottom behind the elements, (see Fig. 1), cannot be protected by means of inslagging. This would be possible if the elements were located on the slagging and charging side, (i.e. 90° rotation).

Considering the above mentioned advantages and disadvantages we find the recommendations from Radex acceptable.

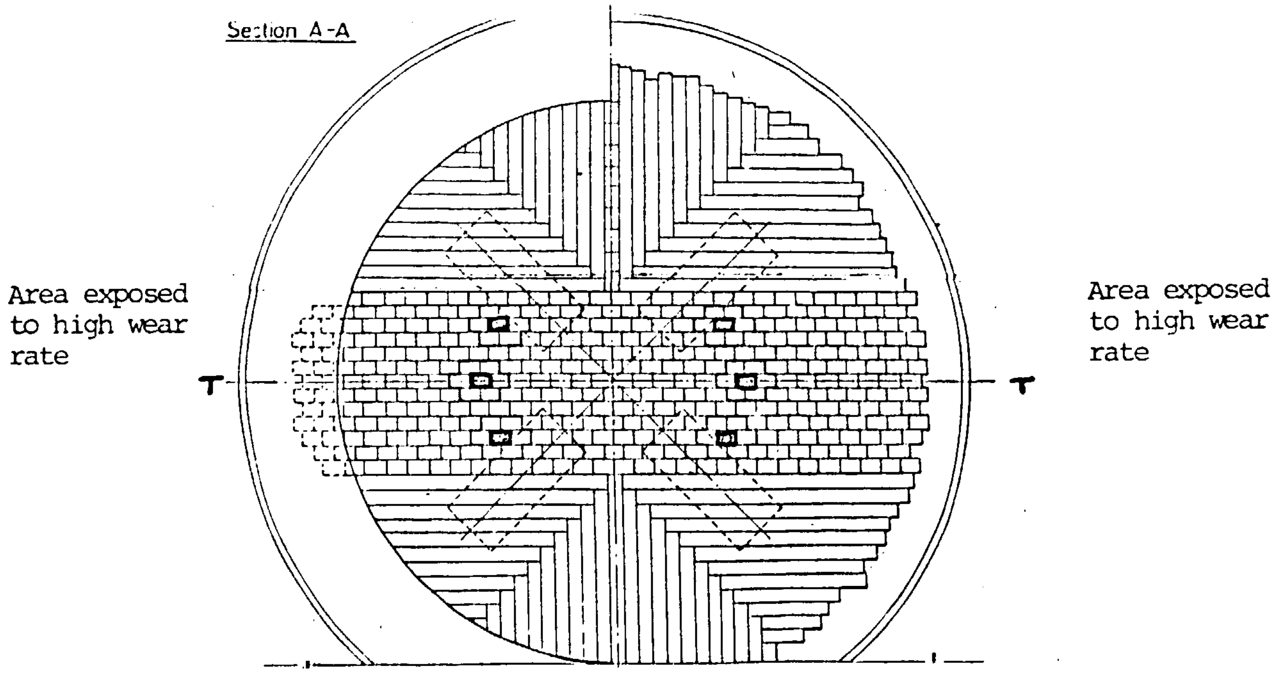

Section A-A
Area exposed to high wear rate
Area exposed to high wear rate
T
T

Figure 1 - Location of permeable elements.

3 Technical comments regarding the draft specification on refractories

Apart from what has been said under point 1 about the junction between barrel and bottom, we have no further comments regarding the lining for curved bottom.

With regard to flat bottom we suggest, for security reasons, that you start with proposal 1.

When you have determined the wear rate of the bottom, it may be better to use a thinner wear lining to balance the wall lining as in proposal 2.

4 Qualities of refractories

We think that the qualities of all refractory are acceptable.

Considering the poor lining life in Bokaro's converter, (180-190 heats), we foresee no problem with the bottom lining life regardless of which proposed solution is chosen. Accordingly we believe that one bottom lining may be used with more than one barrel lining provided the bottom is well maintained after debricking and the area surrounding the permeable elements has been inspected.

Appendix 8

MEFOS
METALLURGISKA
FORSKNINGSSTATIONEN

Forskningsuppdrag	Konto	Datum	Reg nr
UNIDO/INDIA	4449	1985-05-02	MF85041K

SUBJECT: DP/IND/036 - CONTRACT NO 84/66
PILOT-PLANT TRIALS IN MEFOS 6 TONS CONVERTER

by

Pekka Kuusela

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APPENDIX

1 INTRODUCTION

Combined blowing is a new area of converter steelmaking. It has many benefits compared to conventional LD (BOF) steelmaking, eg.;

- lower oxygen content in the steel
- better manganese yield
- better yield for alloying elements
- better sulphur- and phosphorous removal

Combined blowing has been used with many steelmaking converters around the world. The investment costs are quite low compared to the gain achieved. Also better and cleaner steel-qualities can be manufactured due to a good mixing effect. It can be said that in combined blowing the benefits from OBM- and LD-process are combined.

1.1 Background

Combined blowing has many benefits compared with conventional LD-process when working with hot metal with very high silicon- and manganese-content. Slopping and spitting occurs less in combined blowing due to a good mixing effect. Indian hot metal is very high in silicon and manganese. Considering this, combined blowing is expected to be an efficient method of steel production.

1.2 Aim

The aim of these trials was to test several combined blowing systems with Indian raw materials and as a result of these trials to find a suitable combined blowing system for Bokaro Steel Plant conditions.

1.3 Trial-program

A total amount of 15 trials have been performed in MEFOS 6 tons universal converter. Those 15 trials include all the types of combined blowing systems. Those are:

- inert gas through permeable elements
- inert gas through tuyeres
- reactive gas + lime injection through tuyeres

Because the number of trials was 15, and according to these trials the decision to use combined blowing system at Bokaro was to be made, it was decided to do tests as follows:

- 8 trials with nitrogen (N_2) through permeable elements
- 4 trials with nitrogen (N_2) through tuyeres
- 3 trials with oxygen (O_2) + lime-injection through tuyeres. The oxygen amount through the bottom was 25% of total O_2 and the lime amount through the bottom about 20% of total lime.

2 TRIALS

2.1 Equipment

The main equipment used in these trials consisted of:

- a 12 tonne EAF for melting the pig-iron and adjusting the analysis in the hot metal. Melting power is 5 MVA.
- hot metal ladle for transporting
- a 27 ton over-head crane for transporting
- a 6 ton universal converter equipped with combined blowing, Figure 1

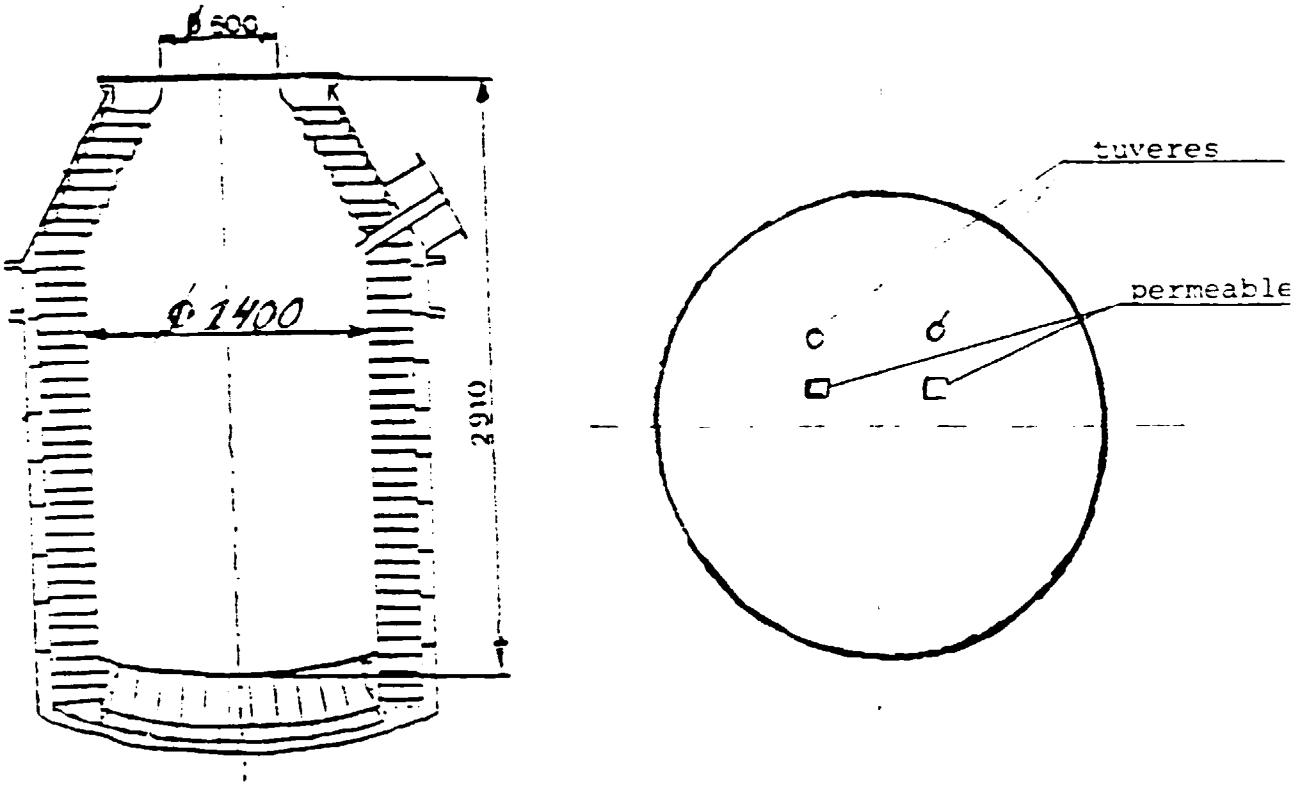


Figure 1 - MEFOS 6 ton converter.

The converter was lined with dolomitic bricks, the bottom was magnesite. In the bottom of the converter two permeable elements and two OBM-tuyeres were installed. Two types of oxygen lances were used in these trials, one for nominal oxygen flow-rate of 15 Nm^3/min (oxygen + lime through bottom-trials) and one for oxygen flow-rate of 17 Nm^3/min (nitrogen through permeables and tuyeres), Figure 2.

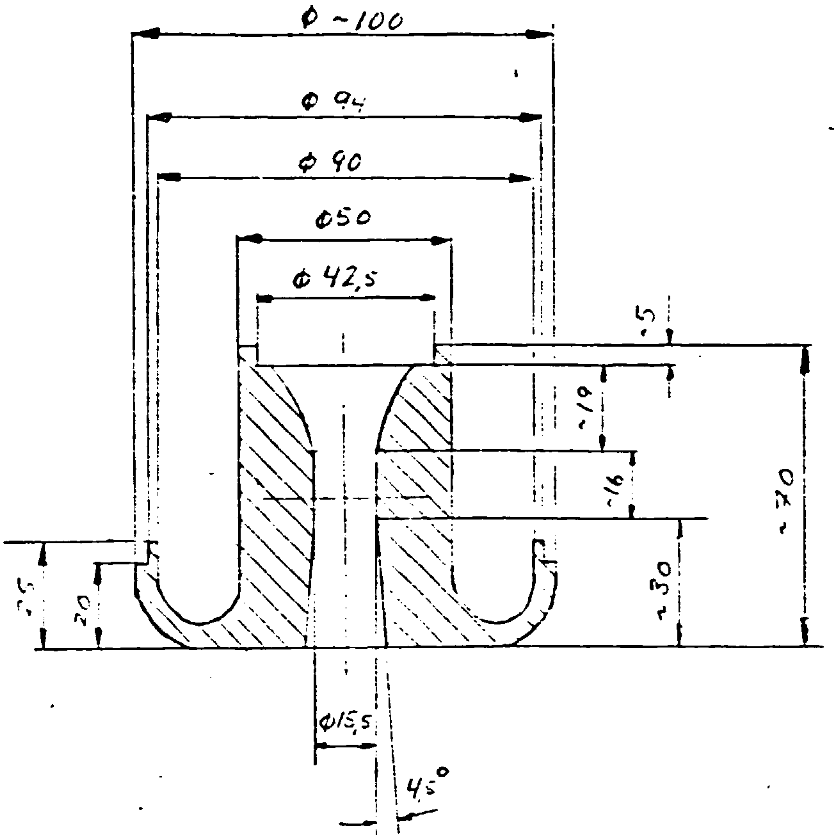

ϕ ~100
ϕ 94
ϕ 90
ϕ50
ϕ 42,5
~5
~19
~16
~70
~30
25
20
ϕ15,5
45°

Figure 2 - 17 Nm^3/min lance tuyere.

- a bin (1 m^3) above the converter for material additions
- off-gases were cleaned in a venturi-scrubber line with a capacity of 21 000 Nm^3/h
- 2.5 ton moulds for casting the charge

A lay-out of gas- and material-system is shown in Figure 3.

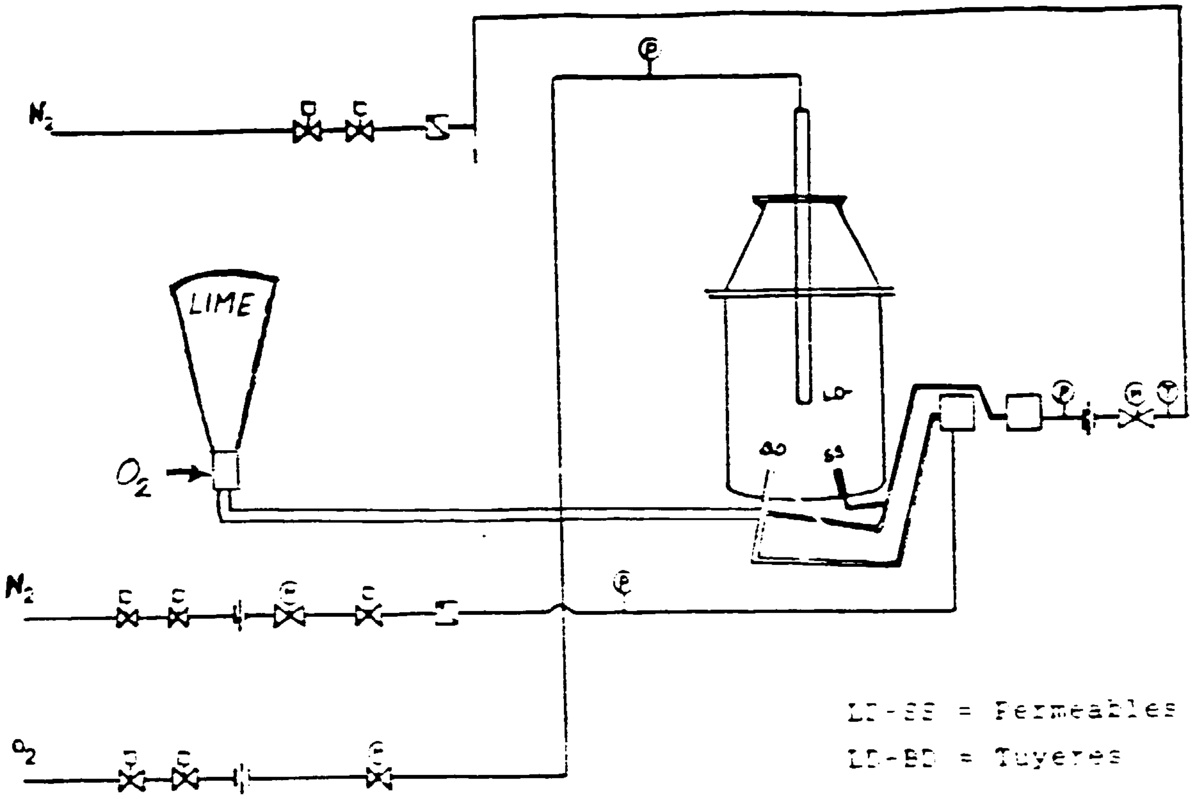

N2
LIME
O2
N2
O2
LD-SS = Permeables
LD-BD = Tuyeres

Figure 3 - Lay-out of gas- and material-system.

2.2 Input material

In these trials the Bokaro conditions were simulated as well as possible. Hot metal analysis was adjusted in the EAF to:

		Variations:
C :	4.0%	3.78-3.97%
Si:	1.6%	1.32-1.66%
Mn:	0.8%	0.65-0.95%
P :	0.300%	0.242-0.385%
S :	0.030%	0.017-0.025%
T :	1270°C	1258-1338°C

Lime used in these trials had the following analysis (lumpy lime):

CaO : 94.0%
SiO_2 : 1.6%
Al_2O_3 : 0.3%
MgO : 1.2%
Fe_t : 0.3%
K_2O : 0.07%
S : 0.009%
LOI : 0.4%
Size : 12-25 mm

To this lime sand (SiO_2) was added to increse the SiO_2-content to 6-7% for simulating the Bokaro conditions.

Scrap had the following analysis: (Billets 100 x 100 mm)

C : 0.13%
Si: 0.12%
Mn: 0.128%
P : 0.027%
S : 0.019%

OBM-lime used had the following analysis:

CaO : 93.5%
SiO_2 : 2.5%
Al_2O_3 : 1.0%
Fe_2O_3 : 0.6%
MgO : 0.8%
Na : 0.1%
K : 0.1%
LOI : 0.7%
S : 0.02%
Size : 100% - 0.25 mm

Manganese-ore was added for slag-formation. It had the following analysis:

MnO_2 : 31.5%
MnO : 18.5%
CO_2 : 14.7%
CaO : 14.0%
MgO : 3.9%
TiO_2 : 0.03%
P : 0.022%

Limestone was added to simulate the LOI in Bokaro. The analysis was:

CaO : 52.1%
CO_2 : 43.0%
SiO_2 : 1.0%
S : 0.2%
MgO : 0.8%
Al_2O_3 : 0.4%
K_2O : 0.09%
Fe_t : 0.18%

Bauxite was added to make the slag more fluid. The analysis was:

Al_2O_3 : 83.9%
SiO_2 : 9.1%
TiO_2 : 4.4%
Fe_2O_3 : 1.1%
CaO : 0.2%
MgO : 0.5%
Na_2O : 0.3%
K_2O : 0.6%

Iron-ore was added in some trials before post-purging for dephosphorization. The analysis was:

Fe_3O_4 : 94.7%
Fe_2O_3 : 1.7%
MnO : 0.06%
CaO : 0.04%
MgO : 0.19%
SiO_2 : 0.13%
TiO_2 : 0.20%
V_2O_5 : 0.18%
P_2O_5 : 0.012%
Na_2O : 0.008%
K_2O : 0.005%
LOI : 0.01%
Fe_t : 71.7%

The input data for each charge is shown in Appendix I and the amounts of each material used is also shown there.

2.3 Carrying through the trials

The trial practice used in different trials is shown beneath:

Process-steps	N_2 (permeable)	N_2 (tuyere)	O_2+lime
Charging the scrap	X	X	X
Charging the hot metal	X	X	X
Bottom-gas flow-rate adjusted	X	X	X
Rising the converter	X	X	X
Lime from the bin	X	X	X
Lance-program	X	X	X
Start injection lime			X
Stop injection lime			X
Lance up	X	X	X
Tilting the converter	X	X	X
Slagging, sampling	X	X	X
Rising the converter	X	X	X
Lance program	X	X	X
Start injection time			X
Stop injection time			X
Lance up	X	X	X
Tilting the converter	X	X	X
Sampling	X	X	X
Post-purging if needed	X		
Sampling, tapping the metal	X		
By-pass flow for the bottom	X	X	X

2.4 Lance-program

In the first trials the Bokaro lance-practice adjusted to MEFOS-converter was used. It did not give a good dephosphorization because of the low FeO-content in the slag and that is why new lance-practices were tried. Lance-practice for each trial is shown in Appendix 3. In Appendix 2 the turn-down data is given for each charge.

2.5 Material additions

Lime-additions into the converter were made according to the Bokaro practice. Limestone and sand were added during the first three minutes of blowing. Manganese-ore was added after 4 minutes of blowing, bauxite was added after about minutes of blowing or about two minutes before slagging according to the Bokaro practice.

In the lime-injection trials the lime flow-rate through the bottom was about 10 kg/min. A total amount of 150 kg of lime was injected and top additions of lime decreased. In some trials iron-ore was added 10 kg before post purging for better dephosphorization in the final end. Also in some trials bauxite was added during the second part of the blowing when the slag was found to be very dry. The amount of additions are shown in Appendix 1.

2.6 Process-control

2.6.1 Sampling and temperature measurement

The following samples have been taken:

EAF: metal- and slag sample, temperature

Converter (rised): metal sample is taken every second minute, slag sample is taken from the frozen slag on the sampling stick if possible, temperature also every second minute

Converter (tilted): metal- and slag-sample, temperature, oxygen-content in the steel, also sample before- and after post-purging is taken

Metal-samples were analyzed for: C, Si, Mn, P, S, Cu, N

Slag-samples were analyzed for: CaO, SiO_2, MgO, MnO, P_2O_5, V_2O_5, Fe_{tot}, Al_2O_3, K_2O, TiO_2, Cr_2O_3, S and C

Metal- and slag-analysis as a function of blowing time is shown in Appendix 20-49 for each charge.

2.6.2 Other measurements

The MEFOS process-control system MEFCON takes care of the process-control. It is based on off-gas analysis and from that analysis several values are calculated. All the ingoing gases and materials are measured and flow-rates logged in computer for calculations.

The off-gas is analysed for: CO, CO_2 and O_2
flow-rate (wet gas Nm^3/h)
temperature

Process-gases for : flow-rate
pressure
temperature

Materials for : flow-rate
analysis
weight of bins or dispensers

From the off-gas analysis the decarburization rate and carbon content of the bath is calculated. Also one metal sample is quick-analyzed (LECO) and the analysis is fed to the computer during the same trial. Computer makes the corrections to calculated values if needed to get the final carbon content in the bath as accurate as possible.

3 RESULTS

3.1 Decarburization rate

The decarburization rate in each trial is shown in Appendix 6-19, where decarburization curves (YAAG) are shown as a function of blowing time. Also the total oxygen flow as a gas (FO2G) and the bottom-gas flow (FO2N) are shown in the same figures. These values are logged every 15 seconds and spared on a floppy-disc and written after each trial.

As it can be seen from the curves the decarburization rate increases to its maximum after 6-7 minutes of blowing, when the silicon-period (I period) is over. After slagging the decarburization rate reaches its maximum almost immediately after the start of the second blowing period. A peak in decarburization curves can be seen after each limestone-addition. Charge 1407 is missing due to a computer-failure during that trial.

3.2 Slag formation

Slag samples are taken from the sticks used for metal sampling. That is why in some trials only two slag samples have been caught. Slag-analysis as a function of blowing time is shown in Appendix 35-49. Also the measured temperature from the bath is shown in the same curves.

The slag was found to be quite dry in first turn-down in the beginning of the trials. In the latter part of the trials a higher lance-practice was used and slag became more fluid (more FeO in the slag) and better dephosphorization was achieved. The silicon period was over after 6-7 minutes of blowing which can also be seen from the analysis of metal-samples (Appendix 20-34).

The P_2O_5-content in the slag reaches its highest value after 5 minutes of blowing and starts to decrease after that. In the final end of the blowing the P_2O_5-content starts again to increase due to a higher FeO-content in the slag. It can also be seen from the metal samples that the phosphorous-content in the metal decreases considerably during the first period, is quite constant during the second period and starts again to decrease in the final end of the blow when the FeO-content in the slag increases.

3.3 Phosphorous removal

Phosphorous removal as a function of slag basicity is shown in Figure 4.

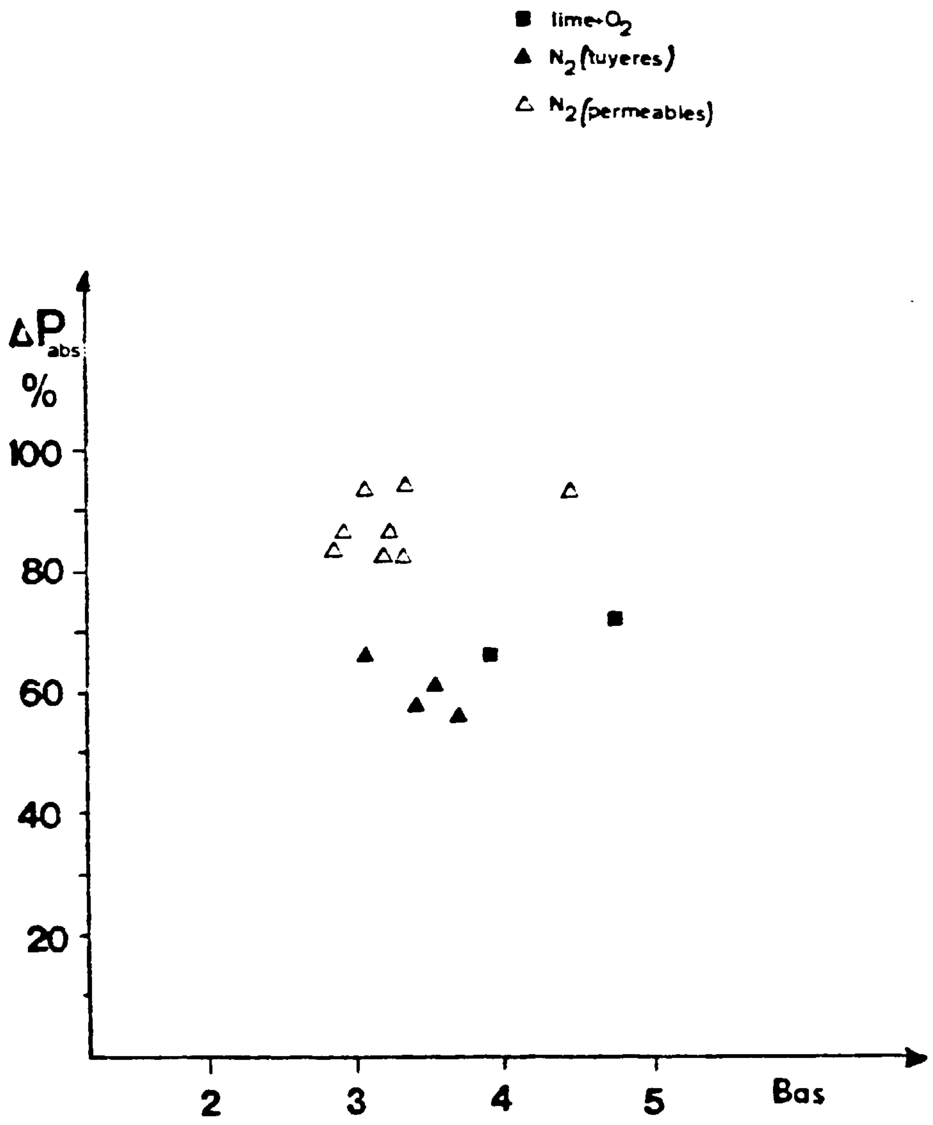


Figure 4 - ΔP_{abs} as a function of basicity (CaO/SiO_2).

As can be seen from Figure 4 the phosphorous removal was best in the trials with permeables (about 80-90%). This is mostly due to the higher lance-practice which was used in the latter part of the trials. The lance-practice from each trial is shown in Appendix 3. The aim basicity in second turn-down was 3.2 and that value has been achieved quite well and lime-yield has been very good. The amount of lime was calculated to Si-content in hot metal 1.6% and that is why in some trials the final slag basicity has been higher due to lower Si-content in hot metal. All the data of ingoing material is shown in Appendix 2.

The effect of higher lance-practice can be seen better in Figure 5 where the phosphorous removal is shown as a function of Fe_t (total iron-content) in the slag.

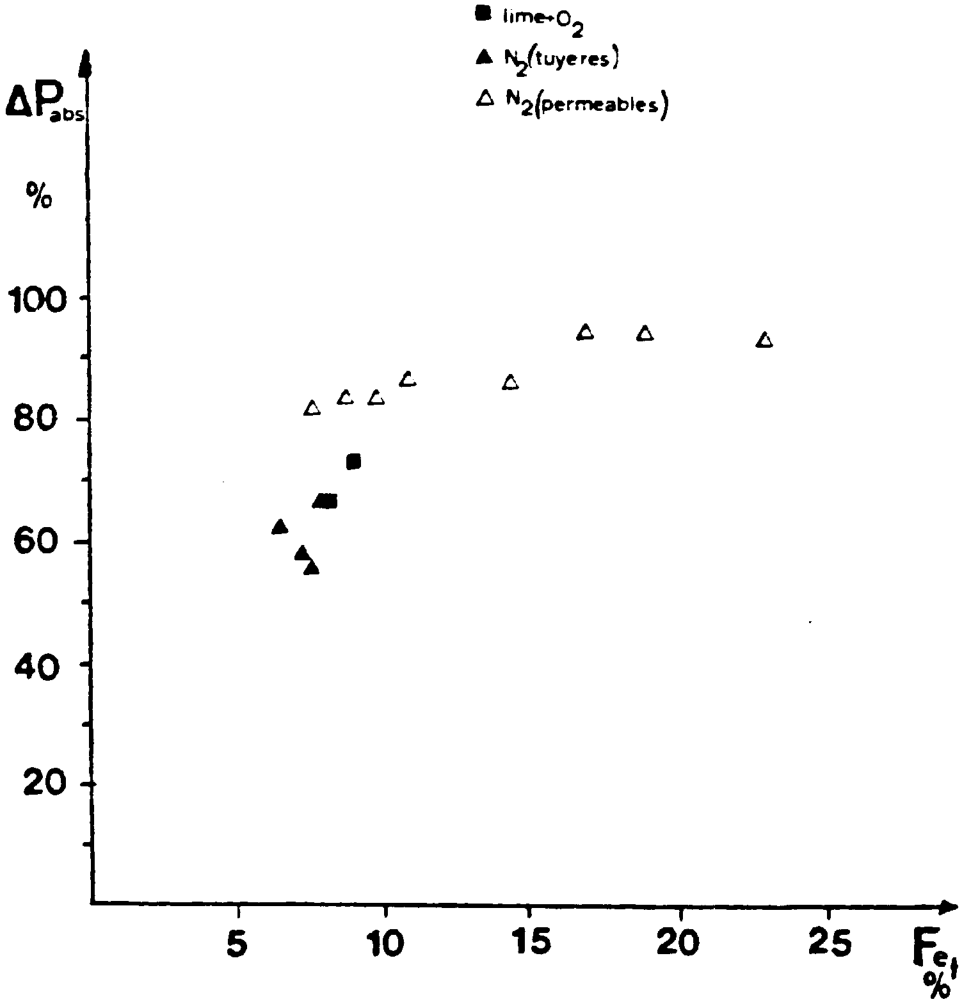


Figure 5 - ΔP_{abs} as a function of total iron (Fe_t) in the slag.

It can clearly be seen from Figure 5 that ΔP_{abs} is better with higher Fe_t-content in the slag, which can be achieved with higher lance-practice. Fe_t content in the slag must be optimized but should not be excessively high because FeO has a negative effect on the refractories.

One slag practice was also tried and in that trial the ΔP_{abs} was 85%. Blowing time in that trial was as long as usual but slagging time was saved in that trials. The lower values of ΔP when nitrogen was injected through tuyeres and oxygen + lime-injection were more due to the Bokaro lance-practice than the effect of tuyeres. In Figure 6 the ΔP_{abs} is shown as a function of tapping temperature.

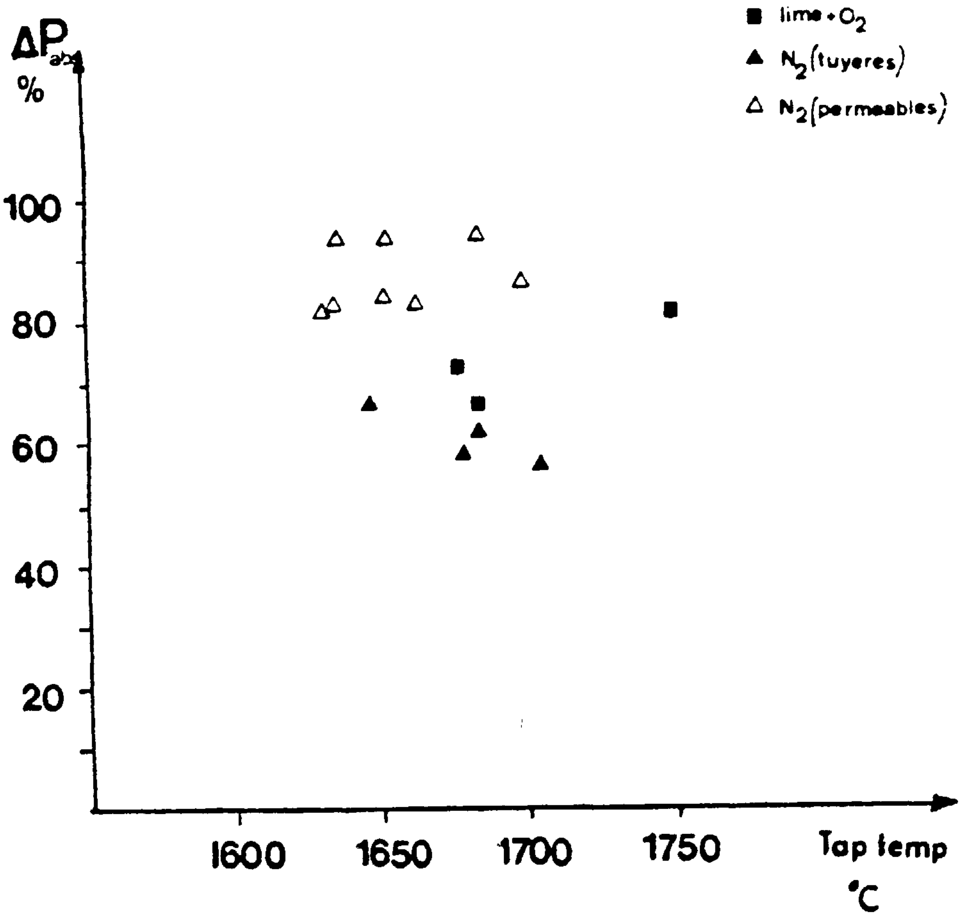


Figure 6 - ΔP_{abs} as a function of tapping temperature.

It can be seen from Figure 6 that the dephosphorization is slightly worse when the tapping temperature is higher.

In Figure 7 the dephosphorization and the desulphurization is shown as a function of the slag-amount per ton hot metal.

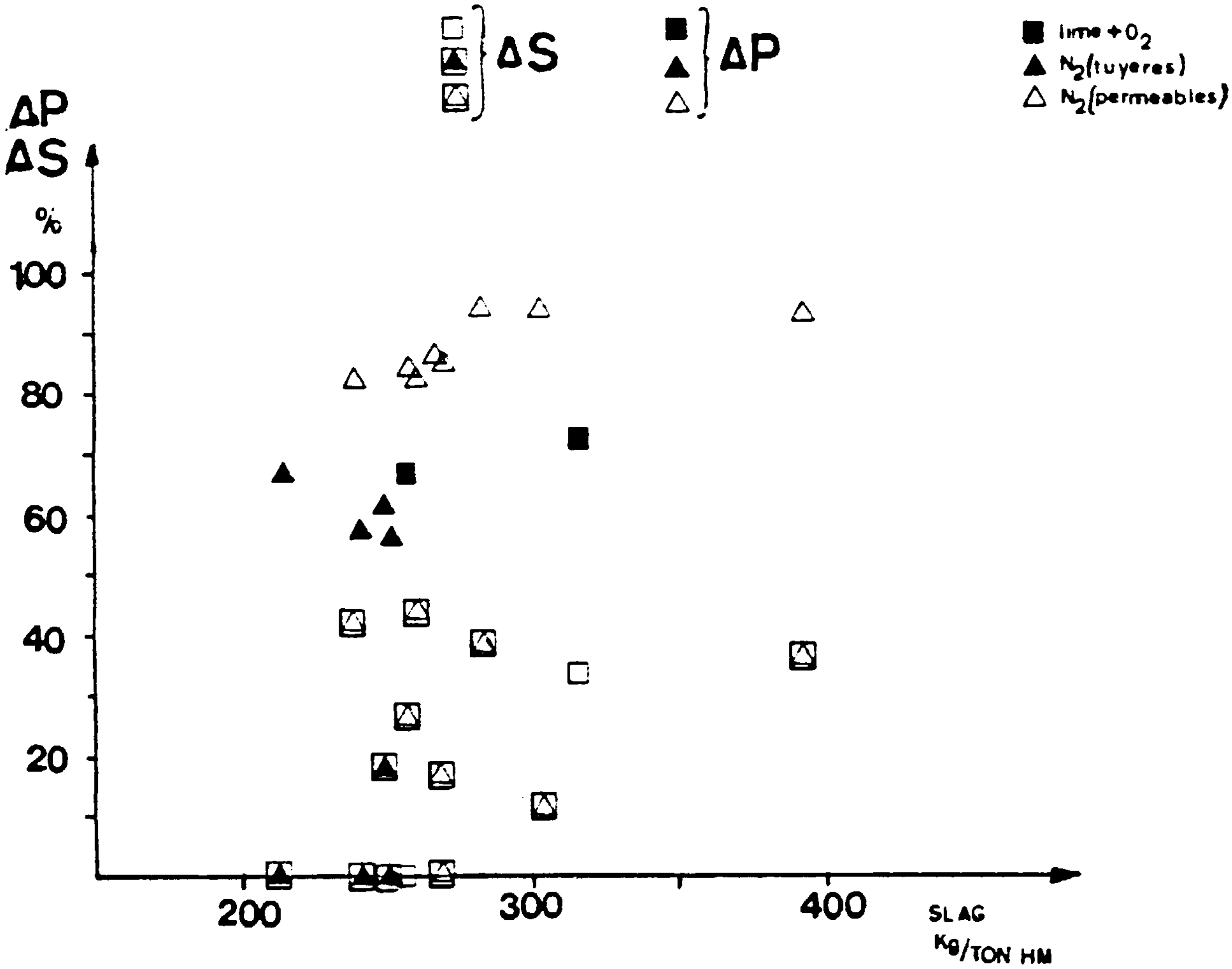


Figure 7 - ΔP_{abs} and ΔS_{abs} as a function of the amount of the slag.

It can be seen from Figure 7 that the dephosphorization is better with higher slag-amounts. The same cannot be said about desulphurization, which seems to be quite independent of the slag amounts. In all these figures one charge (S-1398) is missing due to the fact that final slag-analysis was not available.

3.4 Sulphur removal

The sulphur removal as a function of basicity is shown in Figure 8.

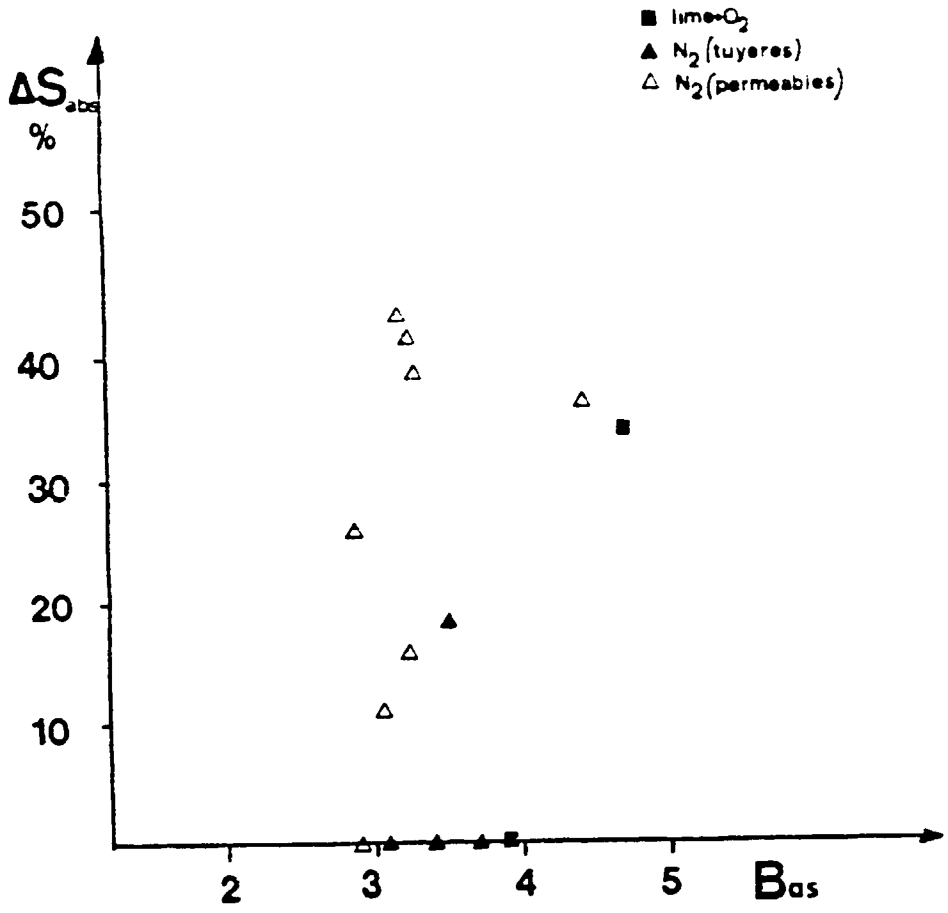


Figure 8 - ΔS_{abs} as a function of basicity (CaO/SiO_2).

It can be seen from Figure 8 that the desulphurization is better with higher basicity. The desulphurization has been 0% in five trials of 15. The best desulphurization is achieved with permeable elements.

3.5 Manganese yield

The manganese yield (Mn_{steel}/Mn_{HM}) as a function of the amount of slag per ton hot metal is shown in Figure 9.

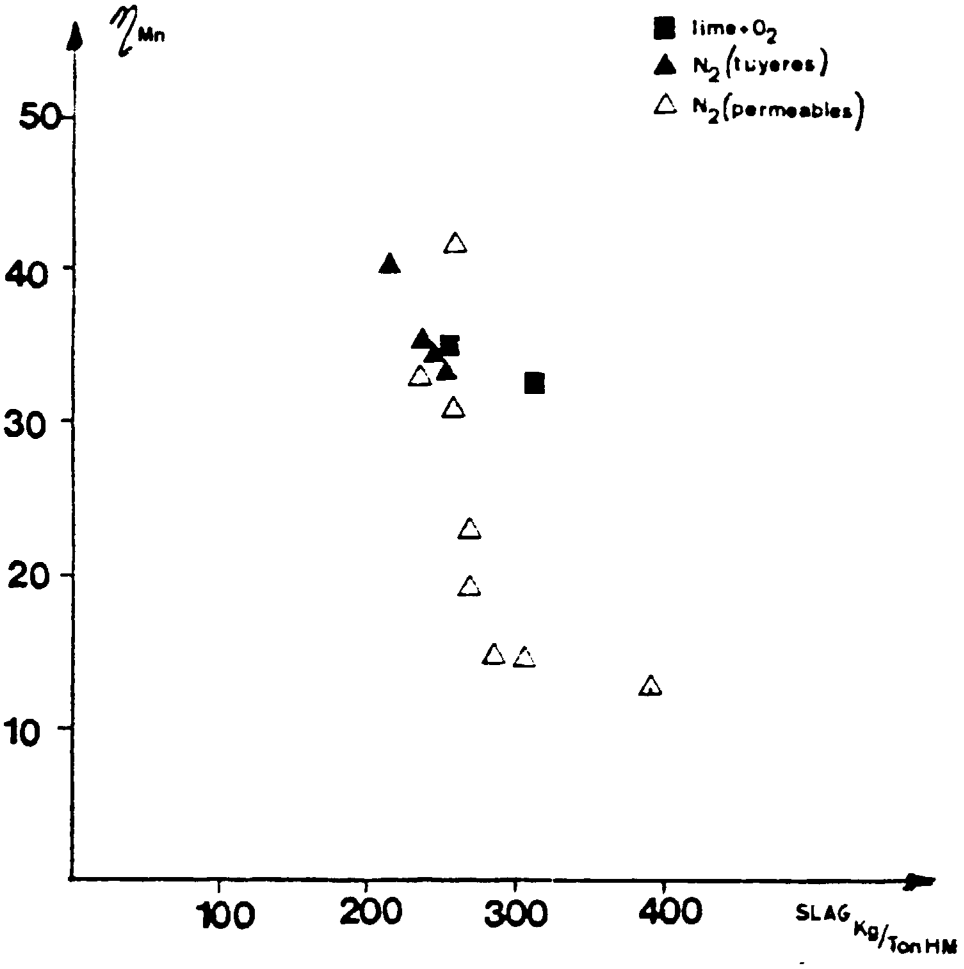


Figure 9 - Manganese-yield as a function of slag-amount.

As it can be seen from Figure 9 that manganese yield is lower with higher slag amounts in all the three type of trials. The lowest values with permeable elements are again due to a better lance-practice and better slag (more fluid slag) which causes more manganese losses to the slag (on the other side better phosphorous removal).

3.6 Iron content in the slag (Fe$_t$) in slag)

Iron content (Fe$_t$) in the slag as a function of carbon content in the steel is shown in Figure 10.

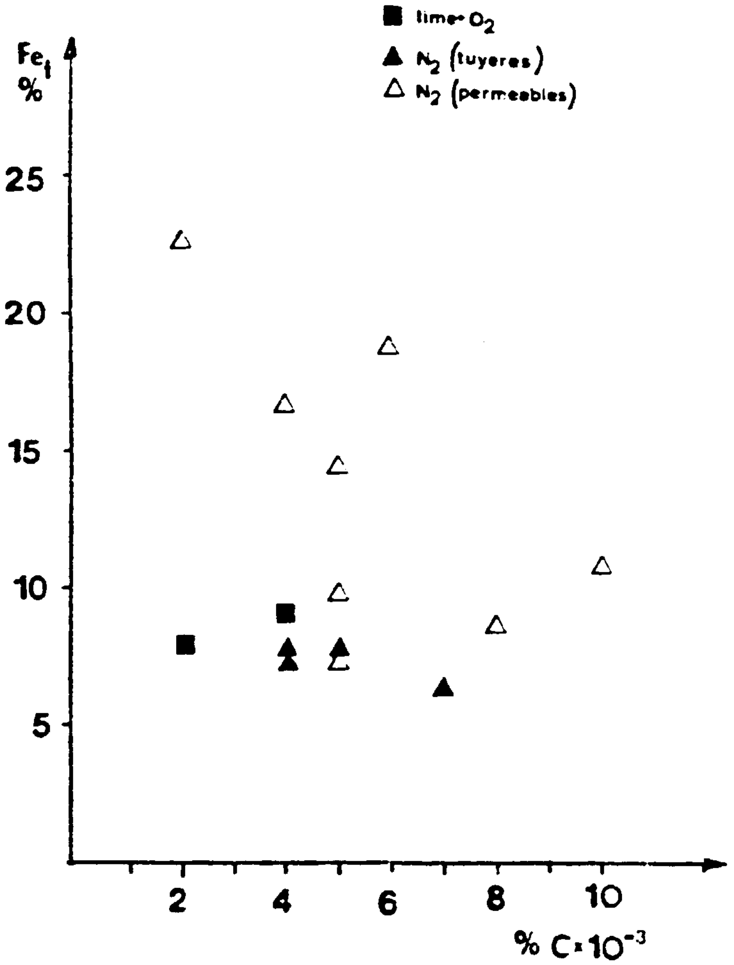


Figure 10 - Fe$_t$ in slag as a function of the carbon content in the steel.

As it can be seen from Figure 10 the Fe$_t$-content in the slag was around 10% in the most of the trials. When the higher lance-practie was used the iron content in the slag increased by about 7-8%, but was always under 23%. It must again be said that iron in the slag is needed for phosphorous removal and in these trials good dephosphorization was achieved with acceptable Fe$_t$-content in the slag.

3.7 Oxygen content in the steel

Oxygen content in the steel was measured with CELOX oxygen-probe. The results of these measurements are shown in Figure 11.

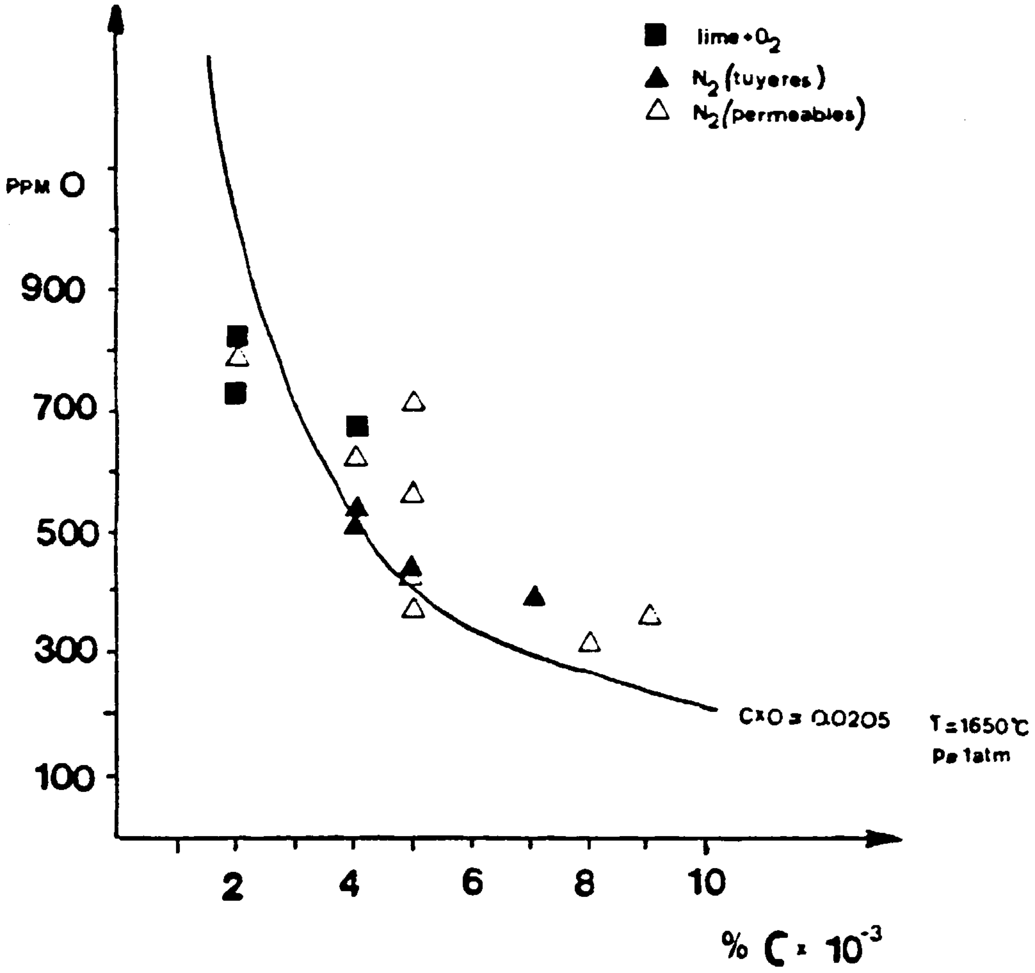


Figure 11 - Oxygen-content in the steel as a function of the carbon content in the steel.

Also the equilibrium-curve C x O = 0.0205 (T = 1650°C, P_{CO} = 1 atm) is given in Figure 11. As it can be seen the oxygen-content in the steel is quite near the equilibrium-curve in each type of trial. The equilibrium-curve C x O for LD steelmaking is about 0,040 and big savings of alloying elements can be made due to the lower oxygen content in the steel. From Figure 11 can also be seen that the effect of combined blowing has been very good in each trial, because the values are quite near the equilibrium. The aim final carbon content was 0.05% and only some of the trials have been over-blown.

3.8 Nitrogen content in the steel

Nitrogen content in the steel is shown in Figure 12 as a function of carbon content in the steel.

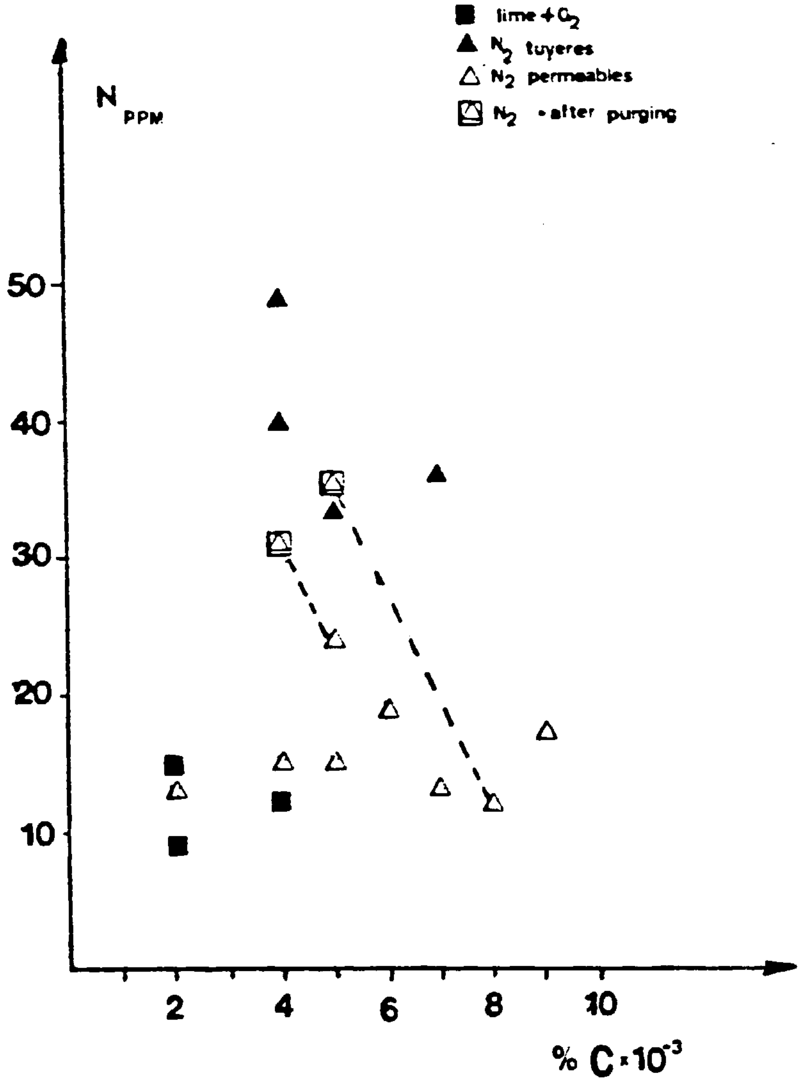


Figure 12 - Nitrogen-content in the steel as a function of carbon content in the steel.

As can be seen from Figure 12 the N-content in the steel is normally about 15 ppm (in case of only oxygen-blowing). The same low values are achieved with permeable elements, where the N-content is around 20 ppm. The highest values of N in the steel occur when nitrogen is injected through tuyeres. Post-purging of nitrogen increased the N-content in the steel with approximately 15 ppm. Different post-purging times were used and the blowing- and post-purging times can be seen from Appendix 1.

3.9 Refractory erosion - MgO-content in the slag

The refractories used in the converter were dolomite (Sindaform T). Bottom was magnesite (Radex ST) and the permeable elements were delivered by Radex (PMOO1). The wear pattern of the converter can be seen from Appendix 5, where the lining is seen both before and after the campaign. The higher lance practice in the latter part of the trials caused erosion higher up in the converter, but the first trials did not cause erosion in the lining. MgO-content in the slag as a function of the basicity can be seen from Figure 13.

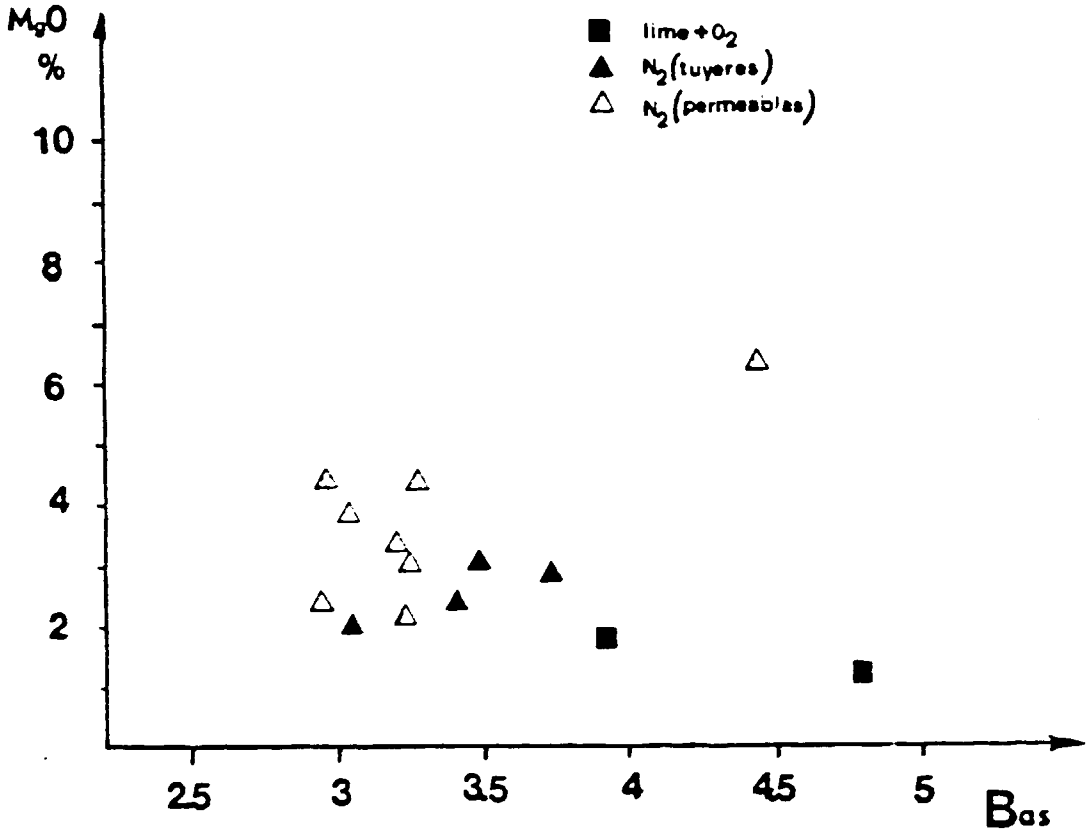


Figure 13 - MgO-content in the slag as a function of basicity.

The MgO-content in the slag is about 3%, which is quite a low value in MEFOS 6 tons converter, because only three trials are usually done per day and after that the converter is waiting for the next day's trials. That causes a lot of erosion due to spalling. No erosion is seen in the bottom and the tuyere region and also the region for permeable elements did not have erosion.

3.10 Scrap-melting velocity

The scrap-melting velocity was studied with copper-marked scrap. Quite a lot of copper removal occured in the converter and only 1/4 of copper-input was found in the steel. The copper-content in the steel reached its highest value usually after 14-15 minutes of blowing so it can be said that all the scrap was melted in that time. This result is not due to a good copper-removal in the converter. All the scrap was melt in turn-down in each trial and no unmelted scrap was found in the tapping.

4 CONCLUSIONS AND RECOMMENDATIONS

15 trials in MEFOS 6 tons combined-blown converter have been made with simulation of Indian raw materials. The aim of the trials was to test different combined-blowing processes and their suitability for Indian conditions and to find the best solution for Bokaro Steel Plant. The different processes tested were:

- oxygen + lime-injection through tuyeres
- nitrogen through tuyeres
- nitrogen through permeables

All these three types of combined blowing processes were found to be suitable for Indian raw material. The Bokaro lance practice which was used in the first part of the trials did not give acceptable dephosphorization and the biggest problem during the trials was to find a good lance practice for this type of raw material. At the end a good slag formation and a good dephosphorization was achieved. The higher lance-practice did not cause much erosion in the upper part of the converter and the MgO-content in the slag remained on an acceptable level in MEFOS-converter. Most of the heats were blown down to 0.04% carbon and in spite of the low carbon content in the steel the Fe_t-content of the slag stayed at an acceptable level. The oxygen content of the steel was low in each charge and values near the equilibrium-curve $C \times O = 0.0205$ (T=1650°C, $P_{CO} = 1$ atm) were achieved.

This means big savings in the consumption of the alloying elements. Also due to a lower oxygen content in the steel the manganese yield was better than in normal LD-practice. The nitrogen content in the steel was about 20 ppm in the case of permeable elements and that is only a little higher N-content than with O_2 + lime-injection. Highest N-contents occured when N_2 was injected through tuyeres. Post-purging of nitrogen increased the N-content of the steel with 5-20 ppm depending on the post-purging time. The studies with the scrap-melting capacity with copper-marked scrap did not give sure values due to a copper-removal in the converter.

4.1 Recommendations for Bokaro Steel Plant

According to the results from the pilot plant tests done in MEFOS 6 ton universal converter we reccommend the following blowing practice to Bokaro Steel Plant:

1 Charging of blast furnace slag to the converter must be avoided.

2 Screening the lime to get rid of lime which is smaller than 10 mm.

3 Combined blowing converter should first be equipped with permeable elements and afterwards there is a possibility to change over to tuyere-based technology.

4 Nitrogen is used as a bottom gas and argon for post-purging (if available), because some nitrogen pick-up was found during the post-purging period.

5 A high lance-practice should be used in Bokaro converter. The first part of the blowing should be done with constant lance-height (160 in our trials, must be calculated to Bokaro converter and lance design), during the second part of the blowing a lower lance-program can be used.

APPENDIX

Appendix 1: Hot metal analysis
Appendix 2: Steel analysis
Appendix 3: Lance-practice
Appendix 4: Calculated values
Appendix 5: Erosion in the converter
Appendix 6-19: Decarburization rate, gas flow-rates
Appendix 20-34: Metal analysis
Appendix 35-49: Slag analysis

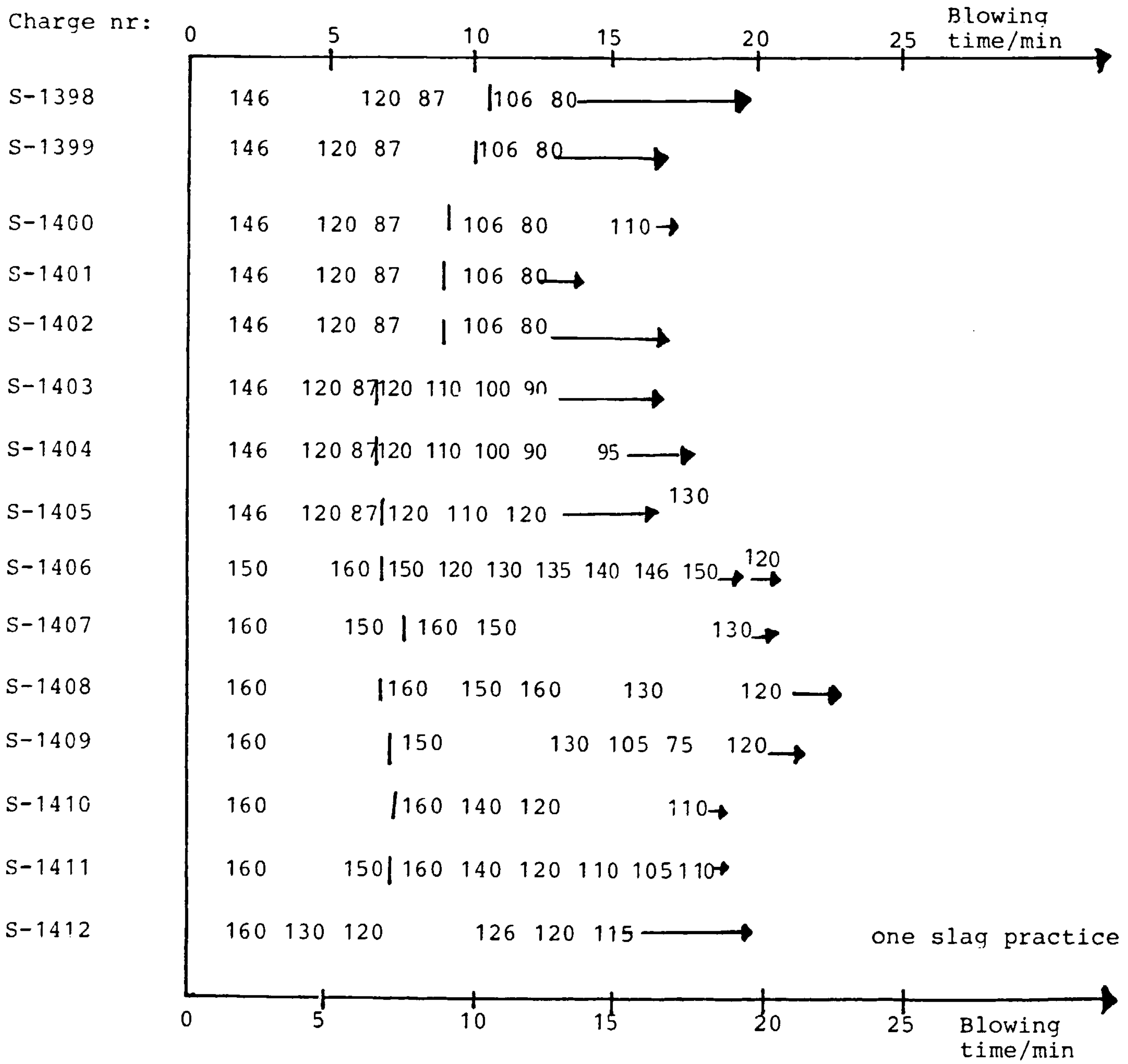
Charge	T °C HM	m HM	Scrap	Lime	OBM-lime	%C	%Si	%Mn	%P	%S	O_2 m^3n	Blowing min+sec	Remarks
S-1398	1338	5060	804	343	154	3.78	1.32	0.79	0.250	0.025		19.30	
S-1399	1360	5210	1006	355	78	3.79	1.51	0.84	0.257	0.022		17	
S-1400	1292	5050	1110	350	157	3.82	1.52	0.86	0.277	0.025	210+68	17	
S-1401	1295	5130	1113	500	-	3.83	1.42	0.85	0.385	0.023		14.00+1.30	Reblown
S-1402	1272	5190	907	500	-	3.91	1.57	0.87	0.233	0.023		17	
S-1403	1261	5090	807	500	-	3.85	1.52	0.93	0.258	0.021		17	
S-1404	1280	5130	798	500	-	3.79	1.58	0.65	0.264	0.020		17.40	Scull
S-1405	1259	4720	802	500	-	3.61	1.56	0.95	0.287	0.017		16.30+0.40	Reblown
S-1406	1277	5230	823	500	-	3.97	1.58	0.86	0.242	0.018		18+1.40	Reblown
S-1407	1263	5120	805	500	-	3.90	1.66	0.84	0.292	0.019		20.15+0.30	Post -P
S-1408	1265	5330	810	500	-	3.86	1.46	0.77	0.268	0.020		19.30+1.00	Post -P
S-1409	1258	4680	813	500	-	3.89	1.34	0.85	0.298	0.020		19.15+1.00	Post -P
S-1410	1280	5340	814	500	-	3.83	1.54	0.71	0.281	0.023		18.45+0.45	Post -P
S-1411	1265	5160	806	500	-	3.93	1.50	0.79	0.278	0.025		18.40+1.00	Post -P
S-1412	1258	5370	815	500	-	3.89	1.51	0.78	0.284	0.022		19.30+1.00	Post -P one slag

Appendix 1

harge	T °C	m kg	%C	%Mn	%P	%S	O ppm	N ppm	Fe_t %	CaO %	SiO_2 %	MgO %	S %	Bas CaO/SiO_2	Remarks
S-1398	1747	4950	0.02	0.24	0.057	0.019	824	15	Not available						
S-1399	1681	5380	0.02	0.29	0.087	0.030	737	9	8.0	55.8	14.3	1.90	0.110	3.9	
S-1400	1675	5090	0.04	0.28	0.077	0.021	659	12	9.0	59.5	12.5	1.20	0.10	4.76	
S-1401	1645	5080	0.05	0.34	0.120	0.029	440	32	7.9	52.9	17.5	.20	0.105	3.02	Reblown
S-1402	1677	5210	0.04	0.31	0.101	0.032	542	40	7.2	56.5	16.6	2.4	0.060	3.40	
S-1403	1704	5170	0.04	0.31	0.115	0.032	520	49	7.5	57.5	15.5	3.9	0.120	3.71	
S-1404	1681	5320	0.07	0.23	0.100	0.026	390	36	6.4	58.0	16.7	3.0	0.090	3.47	Scull
S-1405	1634	5090	0.09	0.20	0.043	0.020	364	17	10.8	49.8	15.5	2.9	0.110	3.21	Reblown
S-1406	1697	5330	0.05	0.16	0.034	0.022	708	13	14.4	44.0	14.9	4.3	0.080	2.95	Reblown
S-1407	1652	5020	0.06	0.12	0.018	0.023	551	19	18.8	41.4	13.6	3.8	0.090	3.04	Post -P
S-1408	1684	5090	0.04	0.11	0.016	0.016	623	15	16.8	44.1	13.5	4.4	0.10	3.27	Post -P
S-1409	1635	5330	0.02	0.12	0.026	0.016	778	13	22.9	40.1	9.1	6.3	0.080	4.41	Post -P
S-1410	1662	5360	0.08	0.30	0.047	0.017	308	12	8.6	51.3	16.1	3.3	0.10	3.19	Post -P
S-1411	1631	5340	0.05	0.26	0.050	0.017	371	31	7.4	52.9	16.3	2.0	0.090	3.24	Post -P
S-1412	1651	5600	0.05	0.24	0.043	0.016	424	35	9.7	49.2	16.7	2.4	0.08	2.94	Post -P one slag

Appendix 3

Lance practice in trials:



The number gives lance height in centimeters above the bath

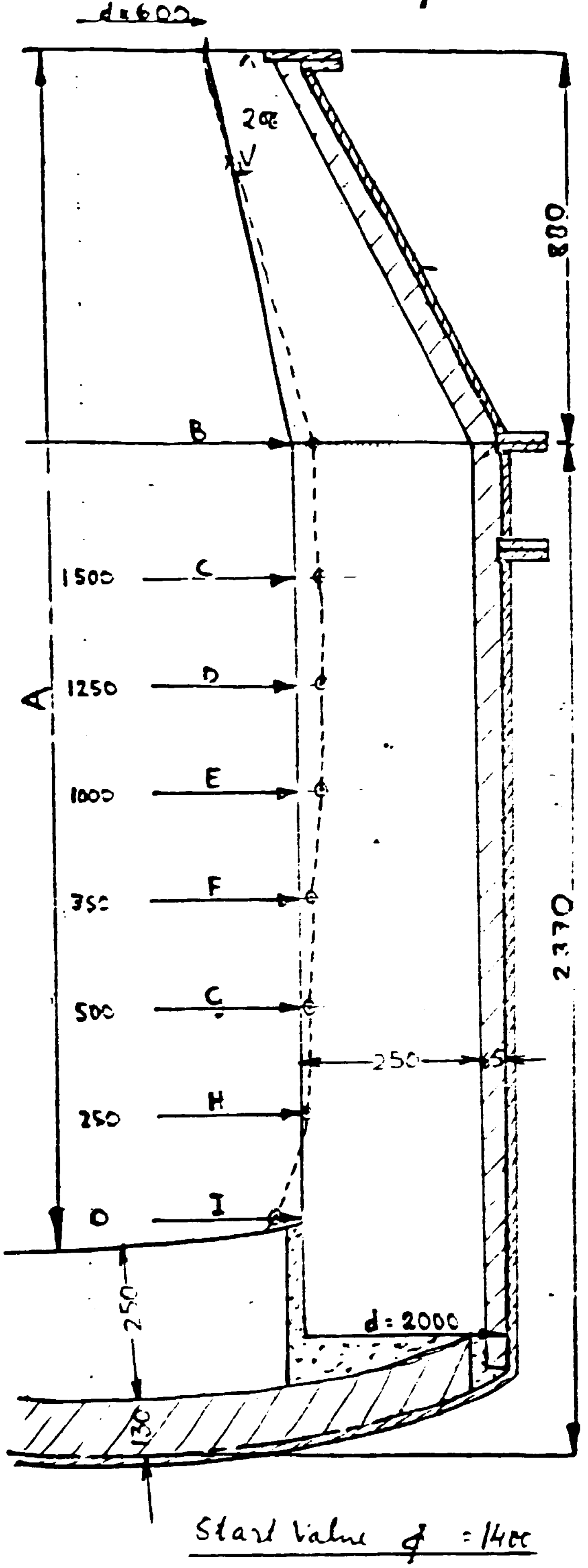
| = means time of first slag tapping

→ = to the final end of blow

Charge	Slag weight		Bas	η_{Mn}	ΔP_{abs}	ΔS_{abs}
	kg	kg/ton HM	CaO/SiO$_2$			
S-1398	not available			30.4	81.3	30.9
S-1399	1339	256	3.9	34.5	65.9	0
S-1400	1581	315	4.76	32.6	72.4	33.0
S-1401	1080	212	3.02	40.0	65.9	0
S-1402	1248	240	3.40	35.6	57.4	0
S-1403	1274	250	3.71	33.3	55.7	0
S-1404	1276	249	3.47	35.4	61.3	18.2
S-1405	1260	267	3.21	23.0	86.0	15.2
S-1406	1402	268	2.95	18.6	85.9	0
S-1407	1552	303	3.04	14.3	93.8	10.3
S-1408	1498	281	3.27	14.3	94.8	38.5
S-1409	1841	393	4.41	12.1	93.2	36.8
S-1410	1392	261	3.19	42.3	81.9	42.2
S-1411	1230	238	3.24	32.9	81.7	41.4
S-1412	1387	258	2.94	30.8	84.5	25.9

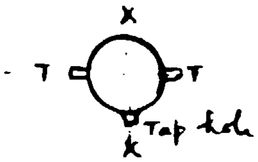
Appendix 5

Dolomit infodring



d=600
20°
V
800
B
1500
C
1250
D
1000
E
750
F
500
G
250
H
0
I
A
250
5
2370
250
130
d=2000

Start value ⌀ = 1400



X
T
T
Tap hole
K

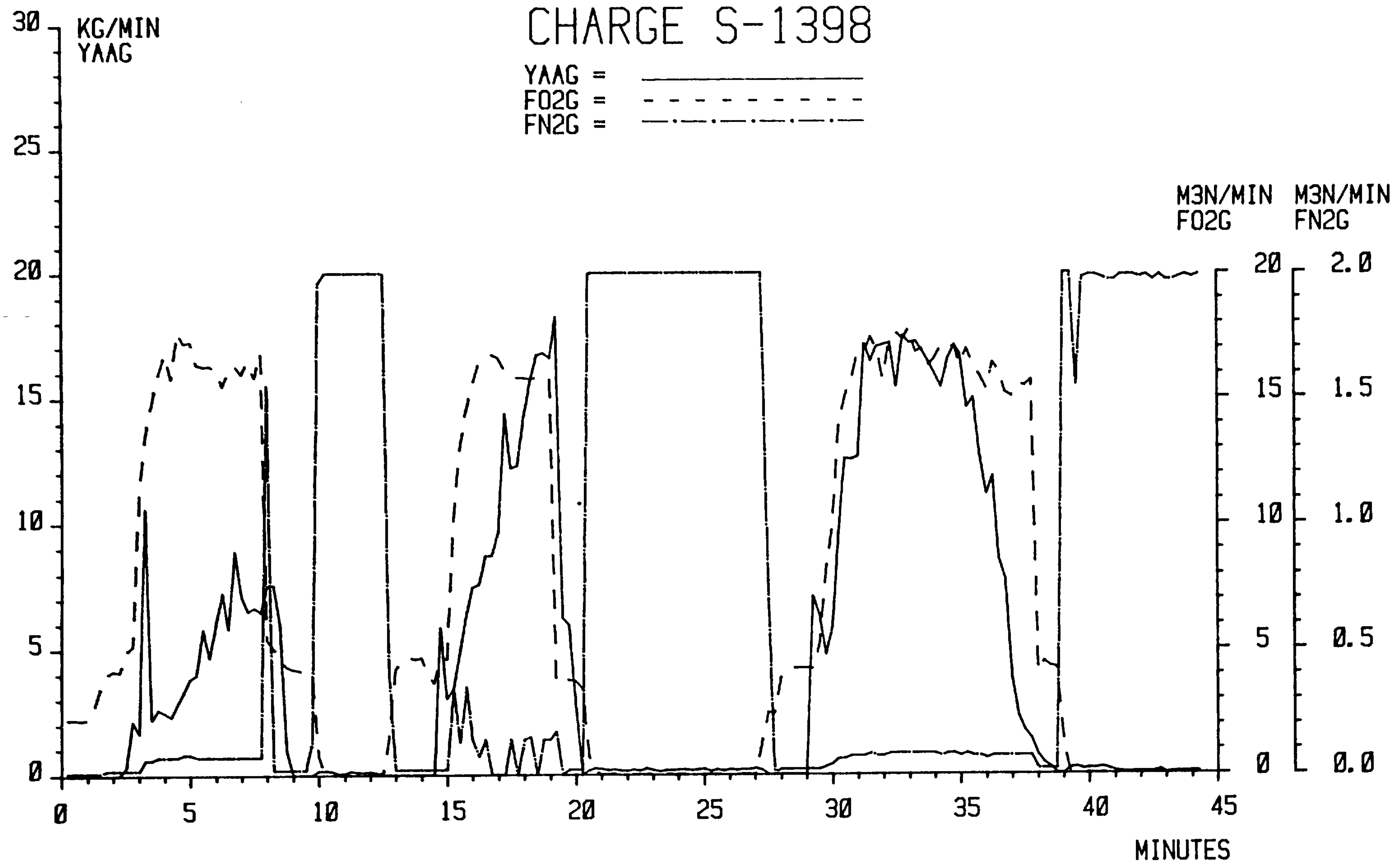
Dimension at

	XX	TT
A	= 2900	= 2900
B	= 1450	= 1450
C	= 1470	= 1466
D	= 1472	= 1468
E	= 1442	= 1440
F	= 1423	= 1408
G	= 1423	= 1413
H	= 1417	= 1391
I	= 1365	= 1362

(Av. worn out lining is shown in dotted line)

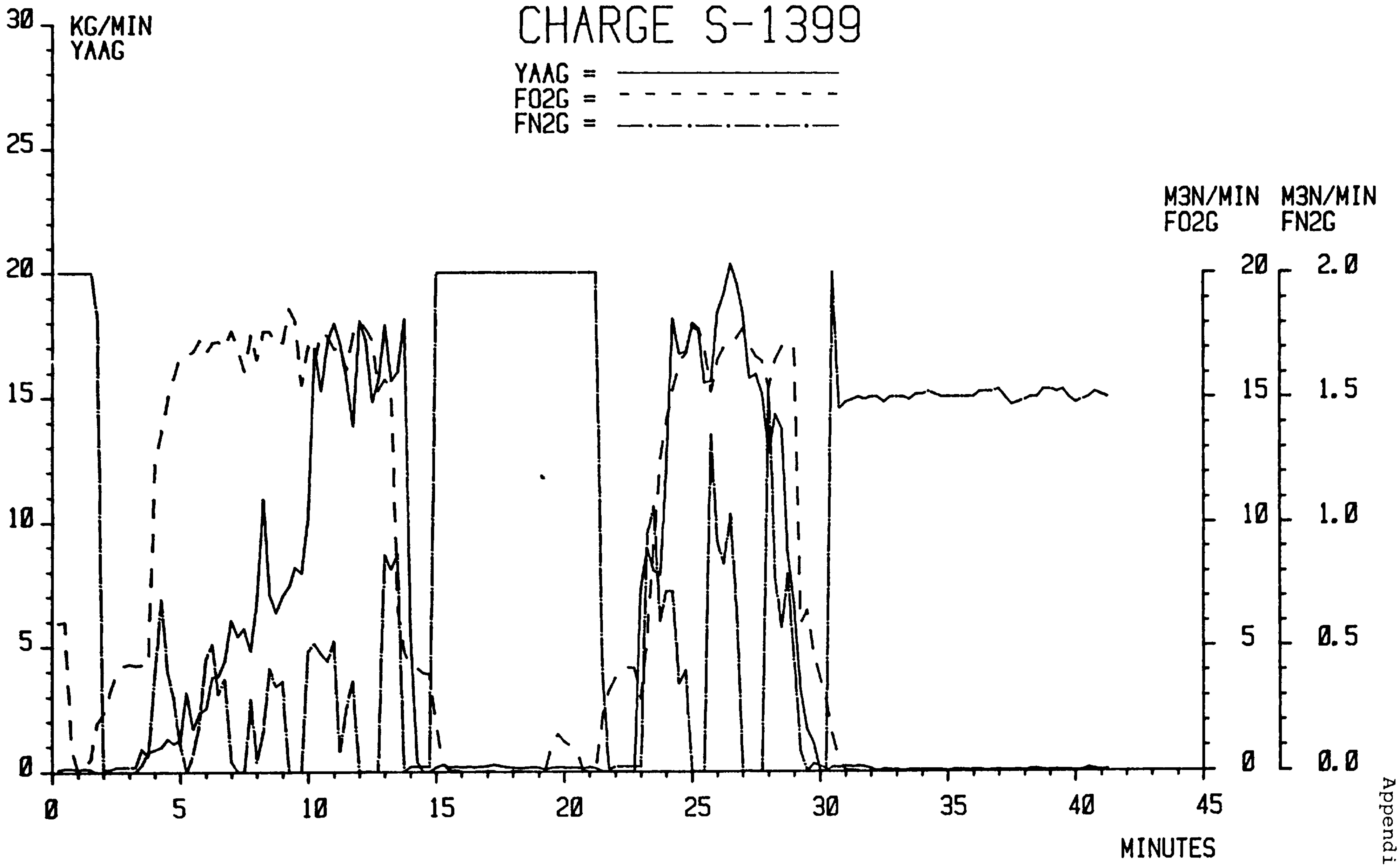
Scale 1:15

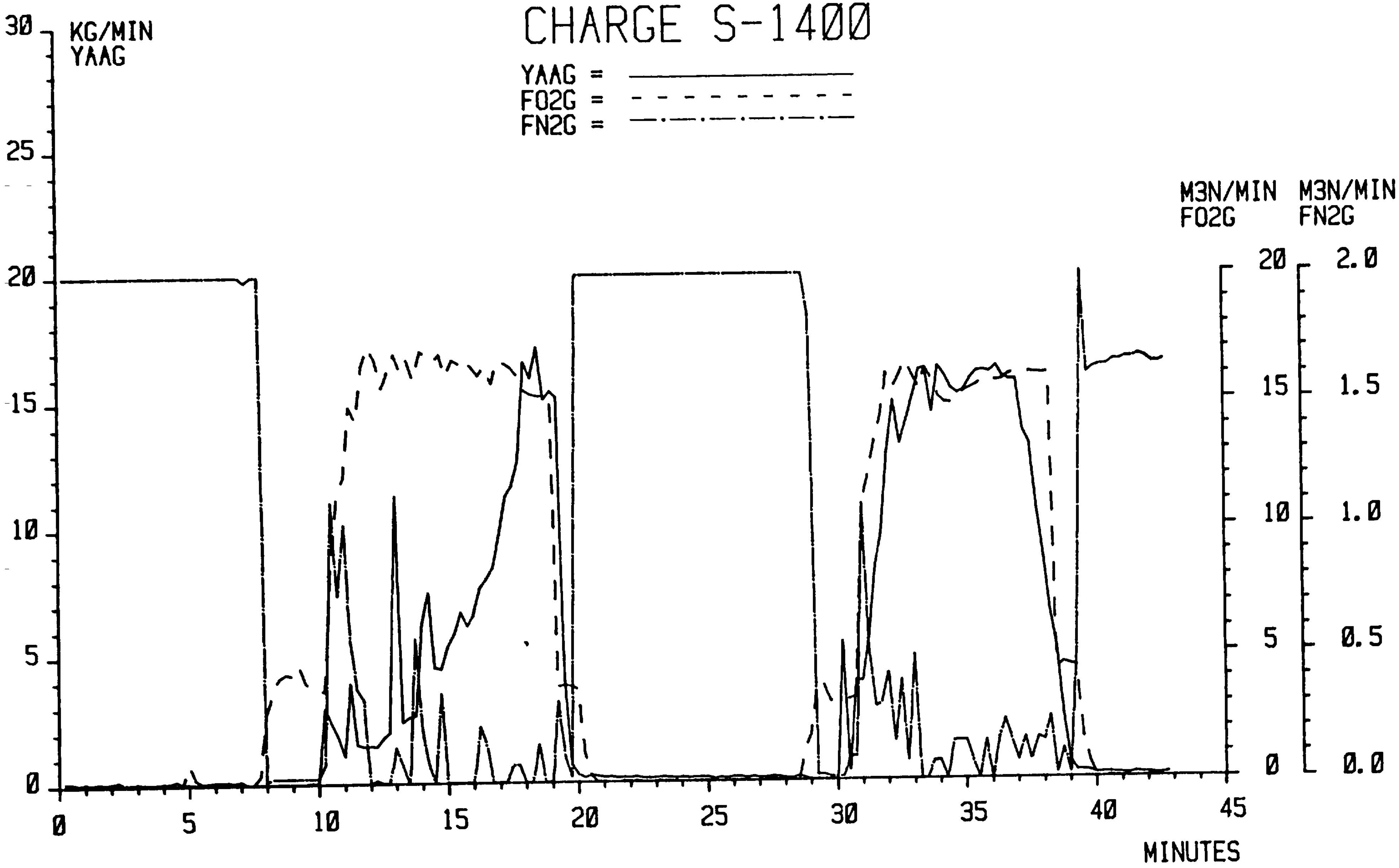
6T CONVERTER
MEFOS, LULEA.

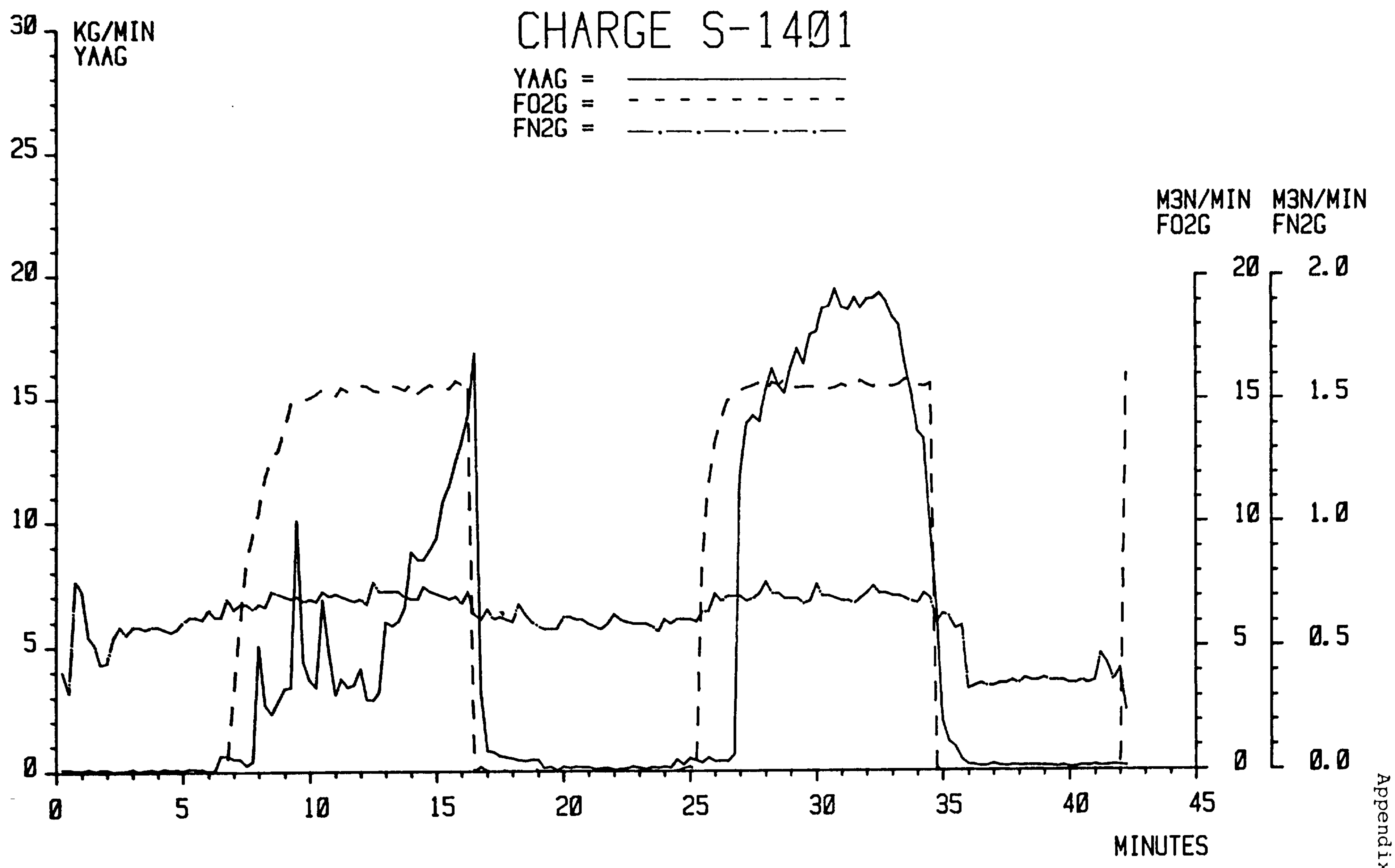


CHARGE S-1398
YAAG =
FO2G =
FN2G =
KG/MIN
YAAG
M3N/MIN
FO2G
M3N/MIN
FN2G
30
25
20
15
10
5
0
20
15
10
5
0
2.0
1.5
1.0
0.5
0.0
0
5
10
15
20
25
30
35
40
45
MINUTES

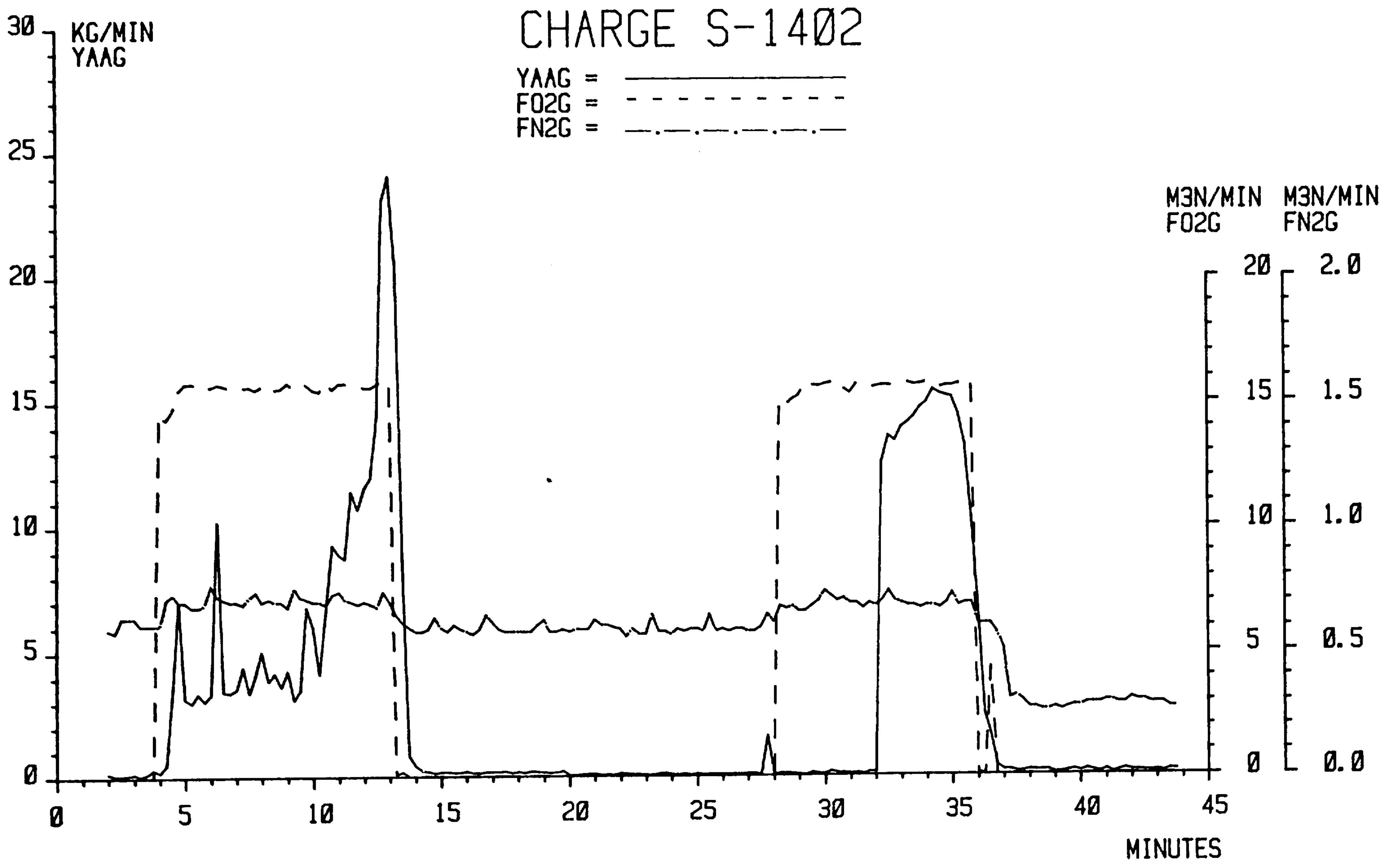
Appendix 6


CHARGE S-1399
YAAG =
FO2G =
FN2G =
KG/MIN
YAAG
30
25
20
15
10
5
0
M3N/MIN
FO2G
M3N/MIN
FN2G
20
15
10
5
0
2.0
1.5
1.0
0.5
0.0
0
5
10
15
20
25
30
35
40
45
MINUTES

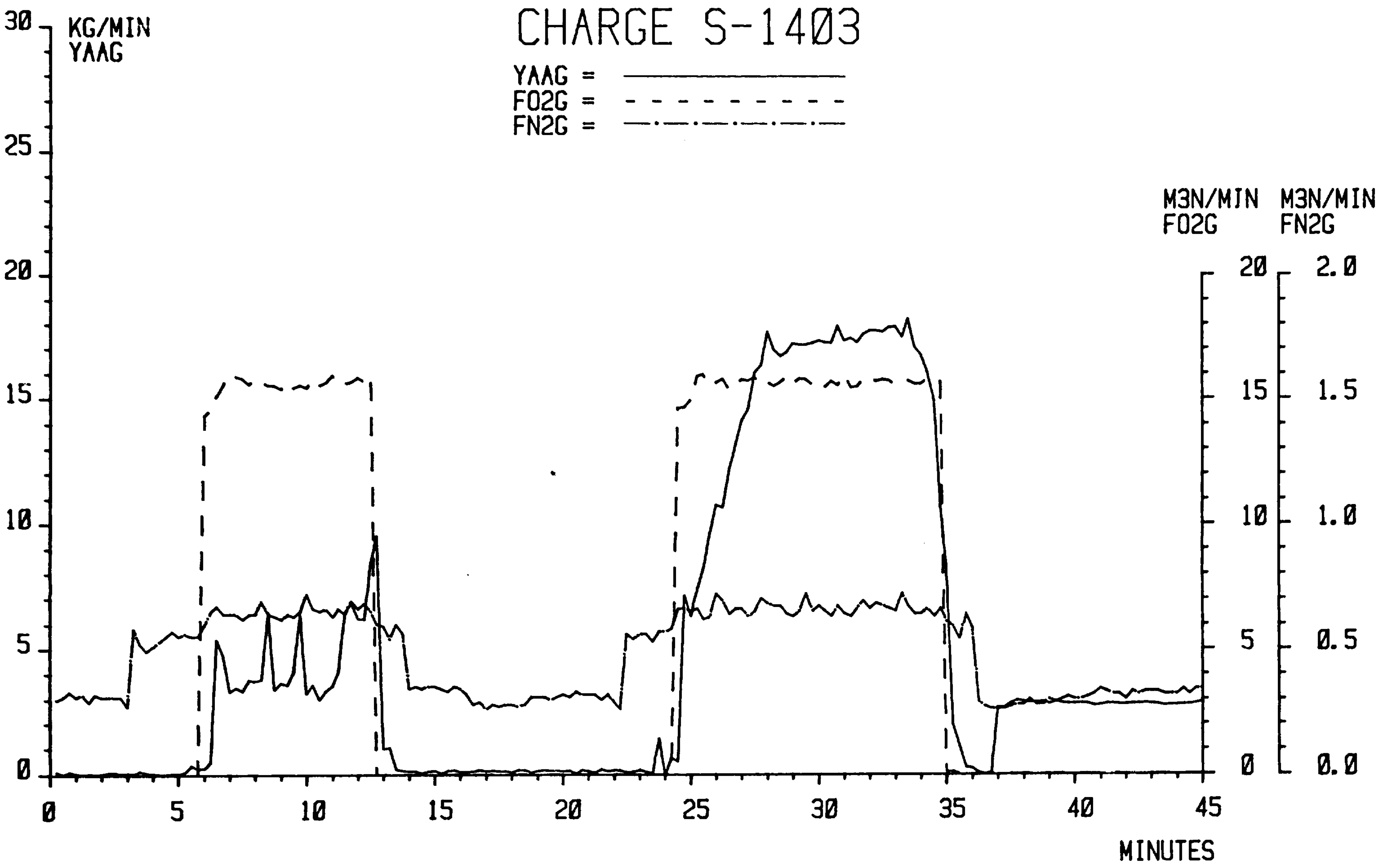
CHARGE S-1400
YAAG =
FO2G =
FN2G =
KG/MIN
YAAG
30
25
20
15
10
5
0
M3N/MIN
FO2G
M3N/MIN
FN2G
20
15
10
5
0
2.0
1.5
1.0
0.5
0.0
0
5
10
15
20
25
30
35
40
45
MINUTES


CHARGE S-1401
YAAG =
FO2G =
FN2G =
30
25
20
15
10
5
0
KG/MIN
YAAG
M3N/MIN
FO2G
M3N/MIN
FN2G
20
15
10
5
0
2.0
1.5
1.0
0.5
0.0
0
5
10
15
20
25
30
35
40
45
MINUTES

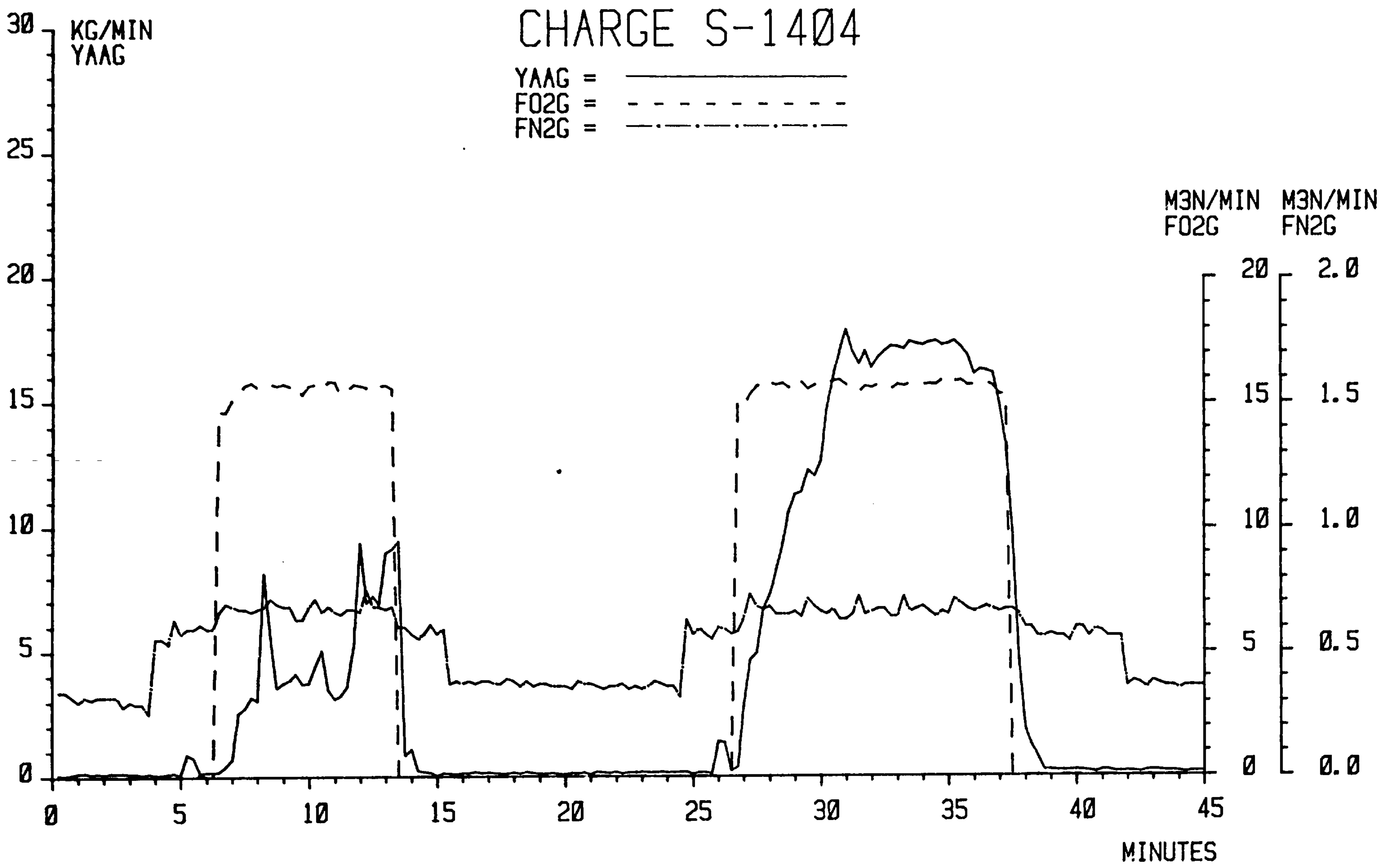
Appendix 9


CHARGE S-1402
YAAG =
FO2G =
FN2G =
30
KG/MIN
YAAG
25
20
15
10
5
0
M3N/MIN
FO2G
M3N/MIN
FN2G
20
15
10
5
0
2.0
1.5
1.0
0.5
0.0
0
5
10
15
20
25
30
35
40
45
MINUTES

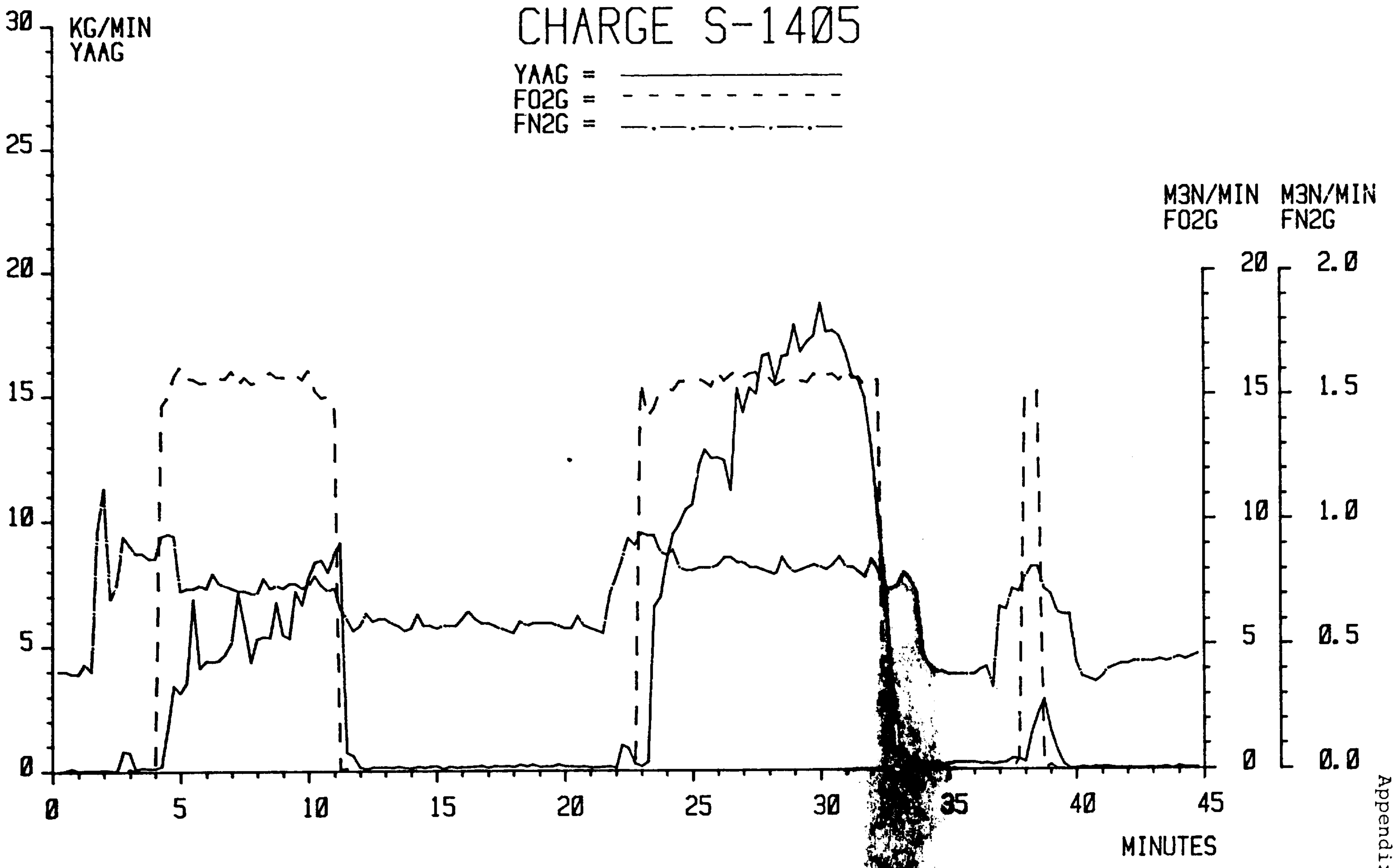
Appendix 10


CHARGE S-1403
YAAG =
FO2G =
FN2G =
KG/MIN
YAAG
M3N/MIN
FO2G
M3N/MIN
FN2G
30
25
20
15
10
5
0
20
15
10
5
0
2.0
1.5
1.0
0.5
0.0
0
5
10
15
20
25
30
35
40
45
MINUTES

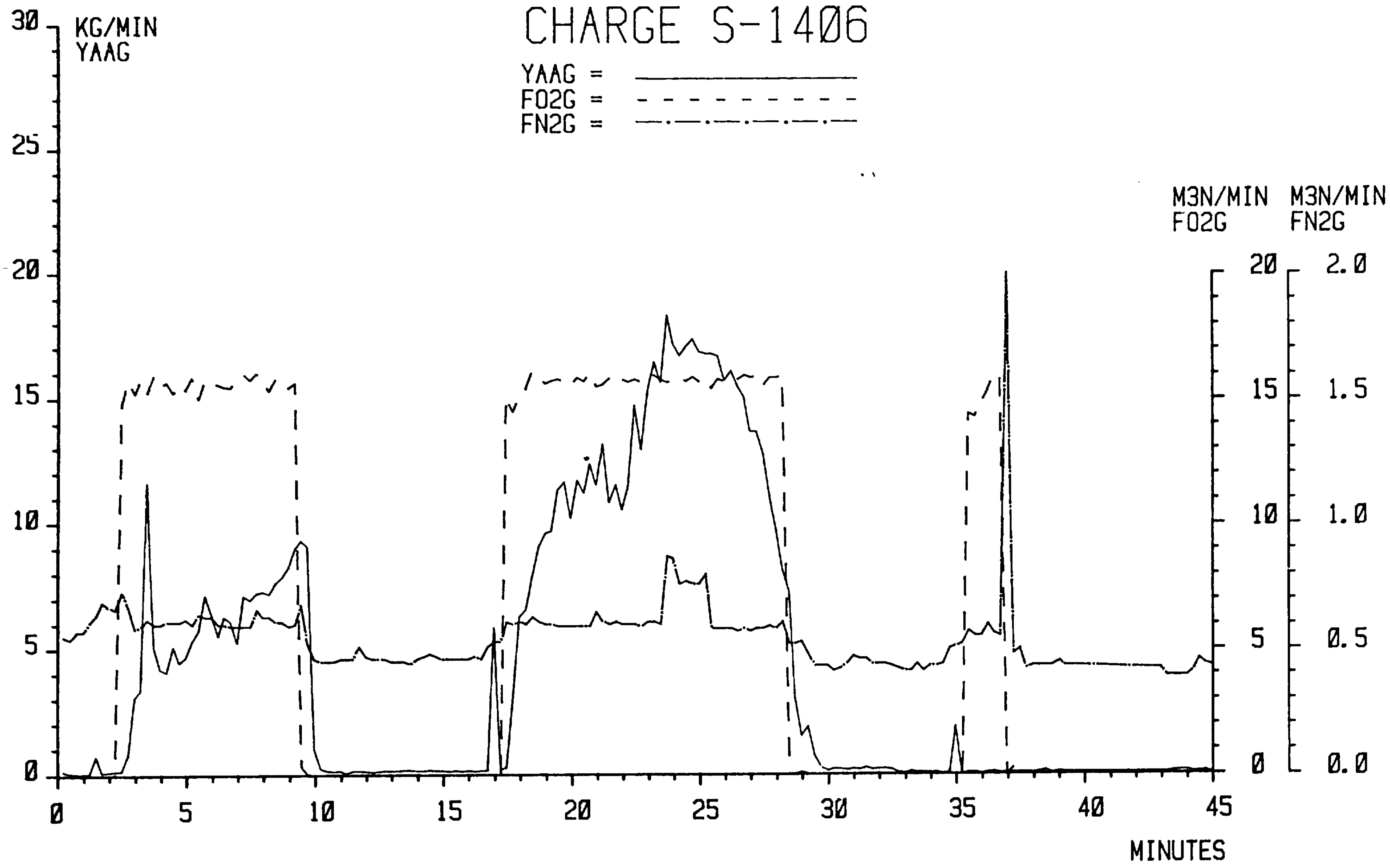
Appendix 11


CHARGE S-1404
YAAG =
FO2G =
FN2G =
KG/MIN
YAAG
30
25
20
15
10
5
0
M3N/MIN
FO2G
20
15
10
5
0
M3N/MIN
FN2G
2.0
1.5
1.0
0.5
0.0
0
5
10
15
20
25
30
35
40
45
MINUTES

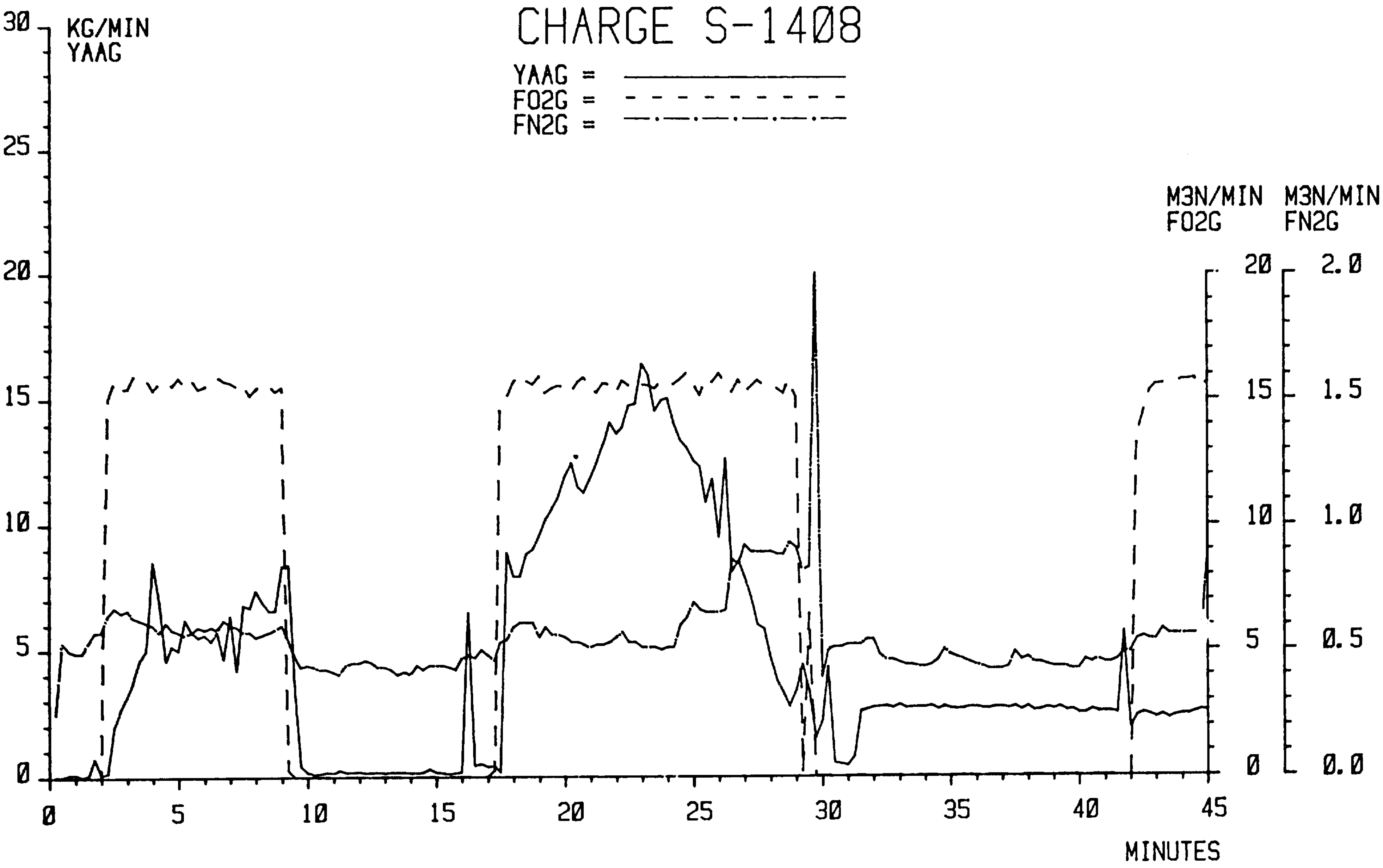
Appendix 12


CHARGE S-1405
YAAG =
FO2G =
FN2G =
KG/MIN
YAAG
30
25
20
15
10
5
0
M3N/MIN
FO2G
M3N/MIN
FN2G
20
15
10
5
0
2.0
1.5
1.0
0.5
0.0
0
5
10
15
20
25
30
35
40
45
MINUTES

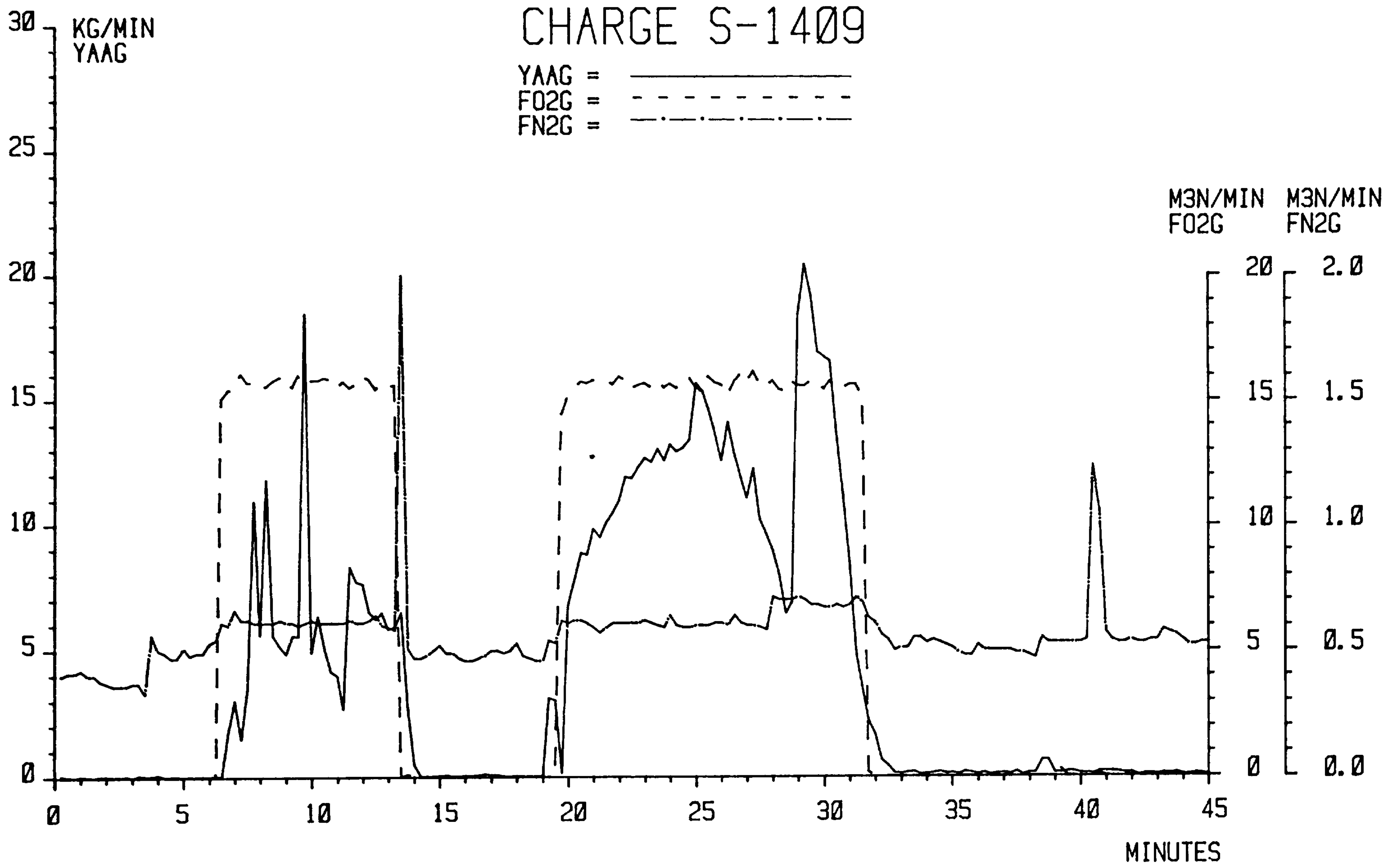
Appendix 13


CHARGE S-1406
YAAG =
FO2G =
FN2G =
30
25
20
15
10
5
0
KG/MIN
YAAG
M3N/MIN
FO2G
M3N/MIN
FN2G
20
15
10
5
0
2.0
1.5
1.0
0.5
0.0
0
5
10
15
20
25
30
35
40
45
MINUTES

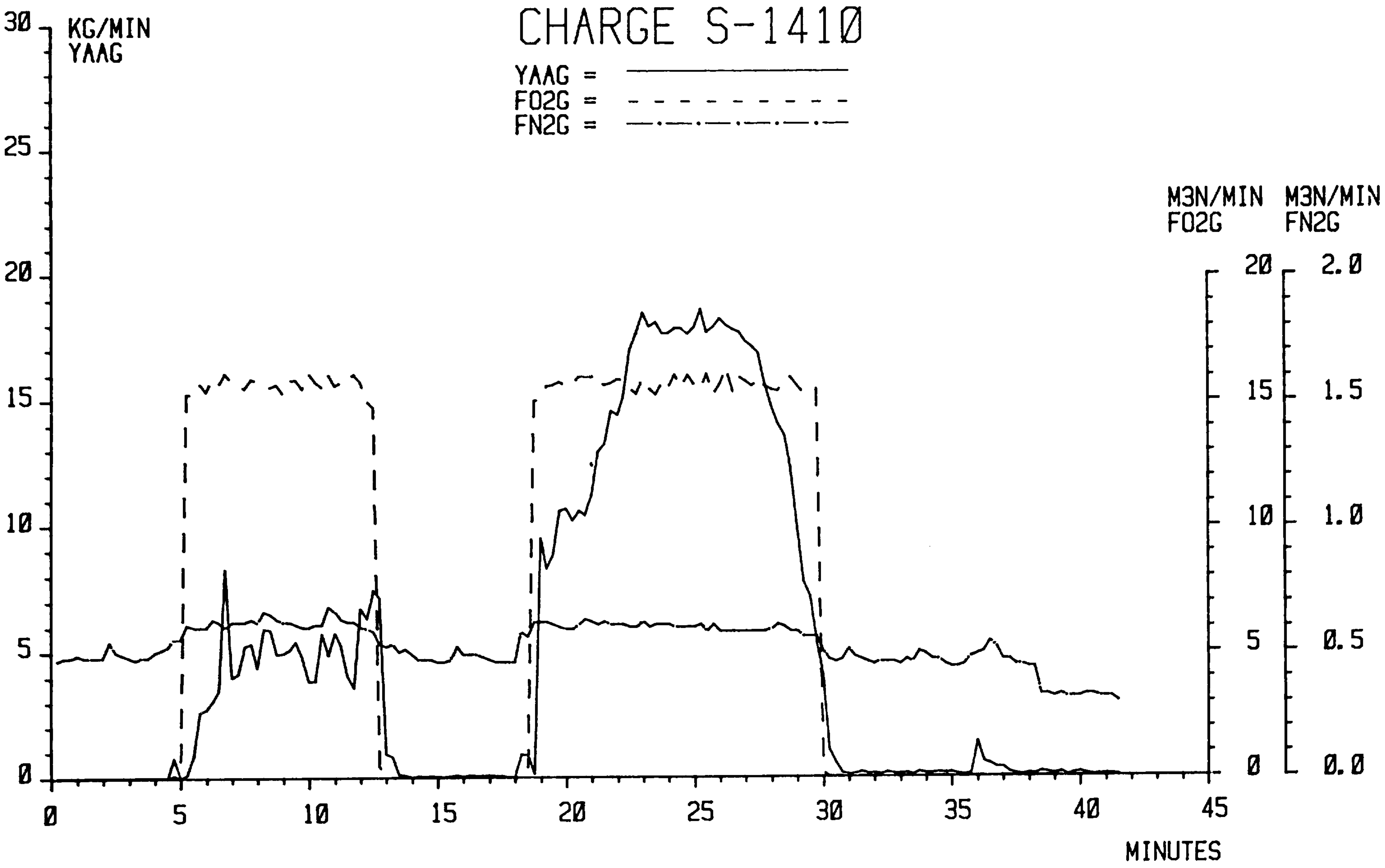
Appendix 14


CHARGE S-1408
YAAG = ————
FO2G = - - - - -
FN2G = —·—·—·—
30
25
20
15
10
5
0
KG/MIN
YAAG
M3N/MIN
FO2G
M3N/MIN
FN2G
20
15
10
5
0
2.0
1.5
1.0
0.5
0.0
0
5
10
15
20
25
30
35
40
45
MINUTES

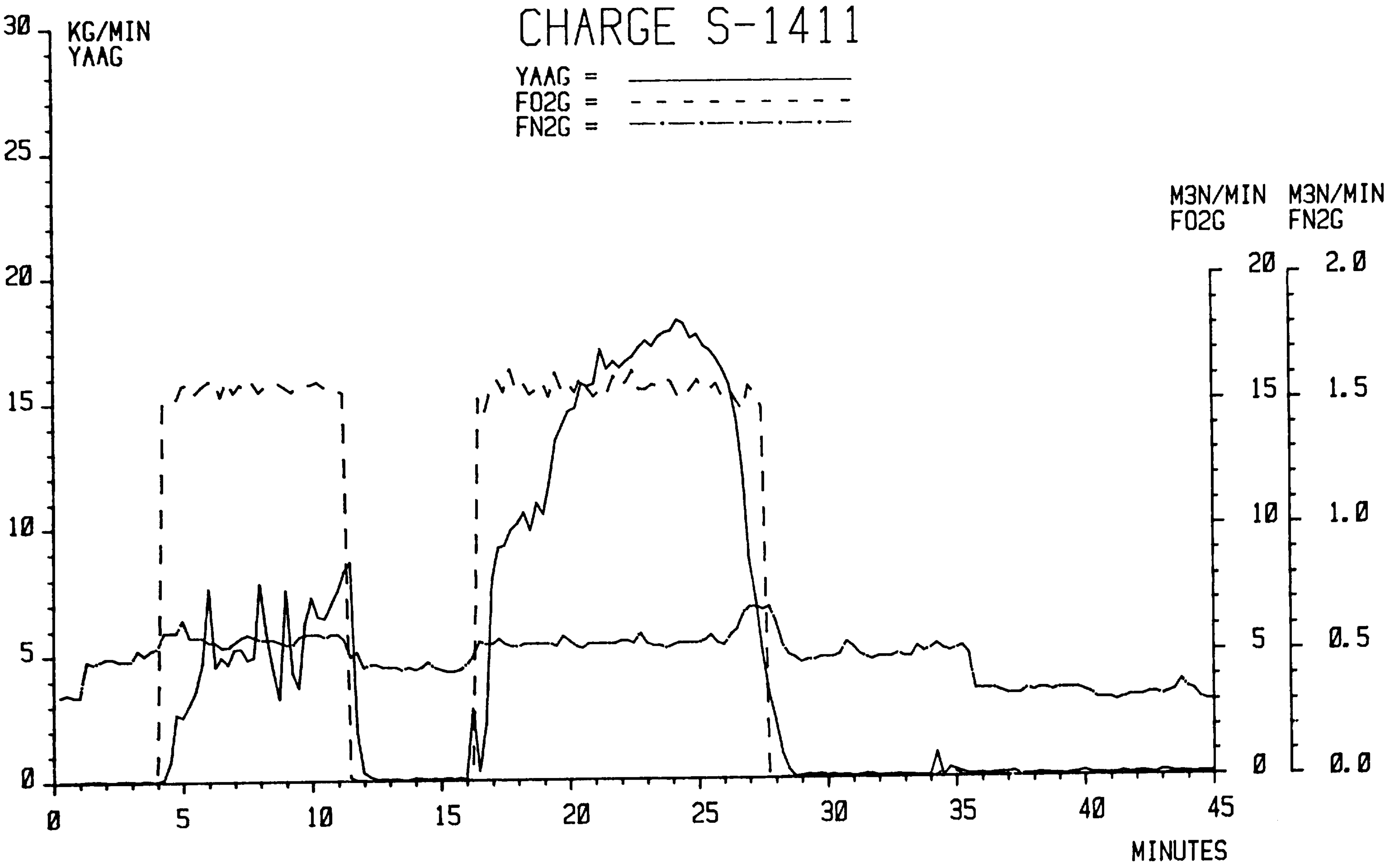
Appendix 15

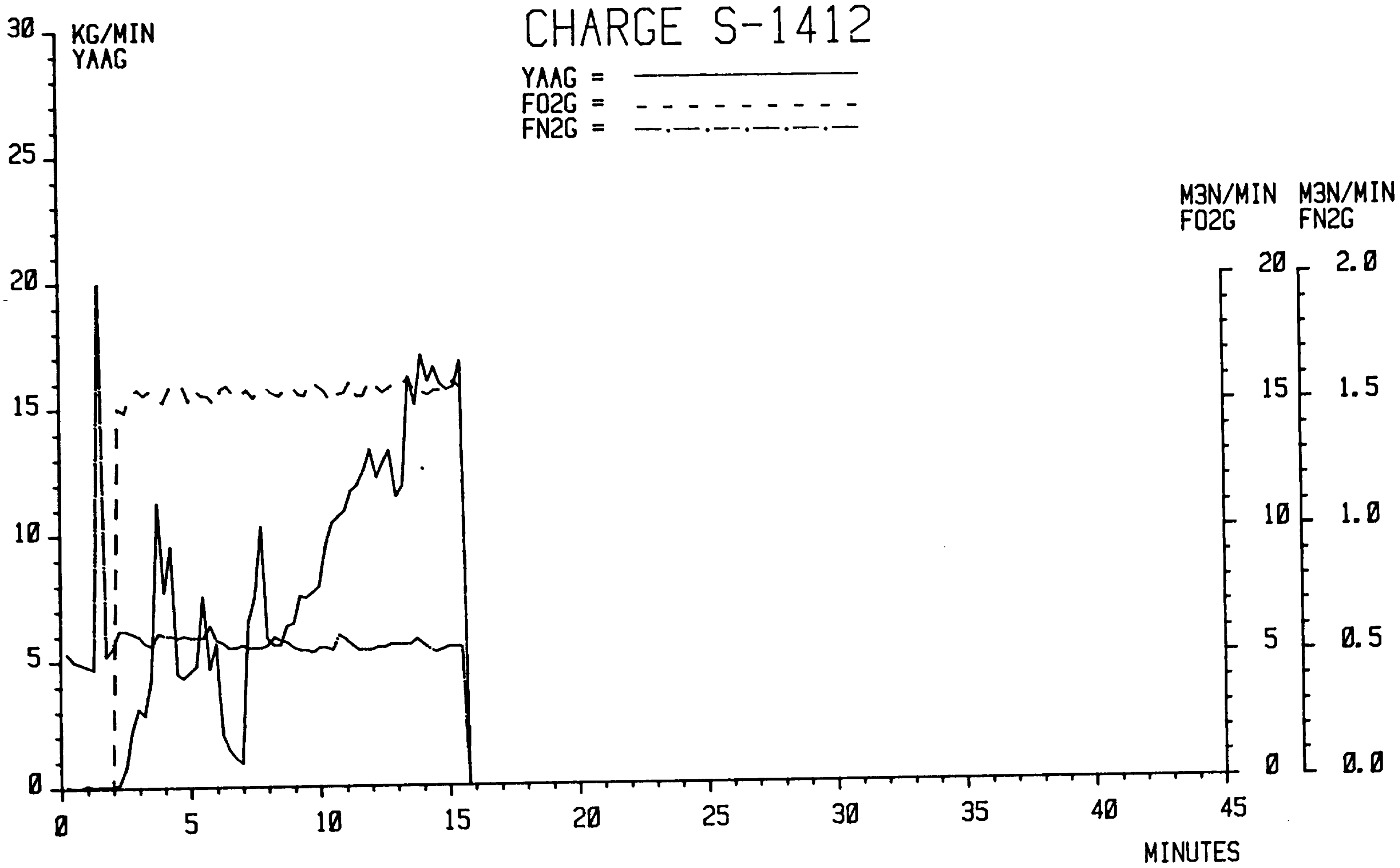

CHARGE S-1409
YAAG =
F02G =
FN2G =
KG/MIN
YAAG
30
25
20
15
10
5
0
M3N/MIN
F02G
M3N/MIN
FN2G
20
15
10
5
0
2.0
1.5
1.0
0.5
0.0
0
5
10
15
20
25
30
35
40
45
MINUTES

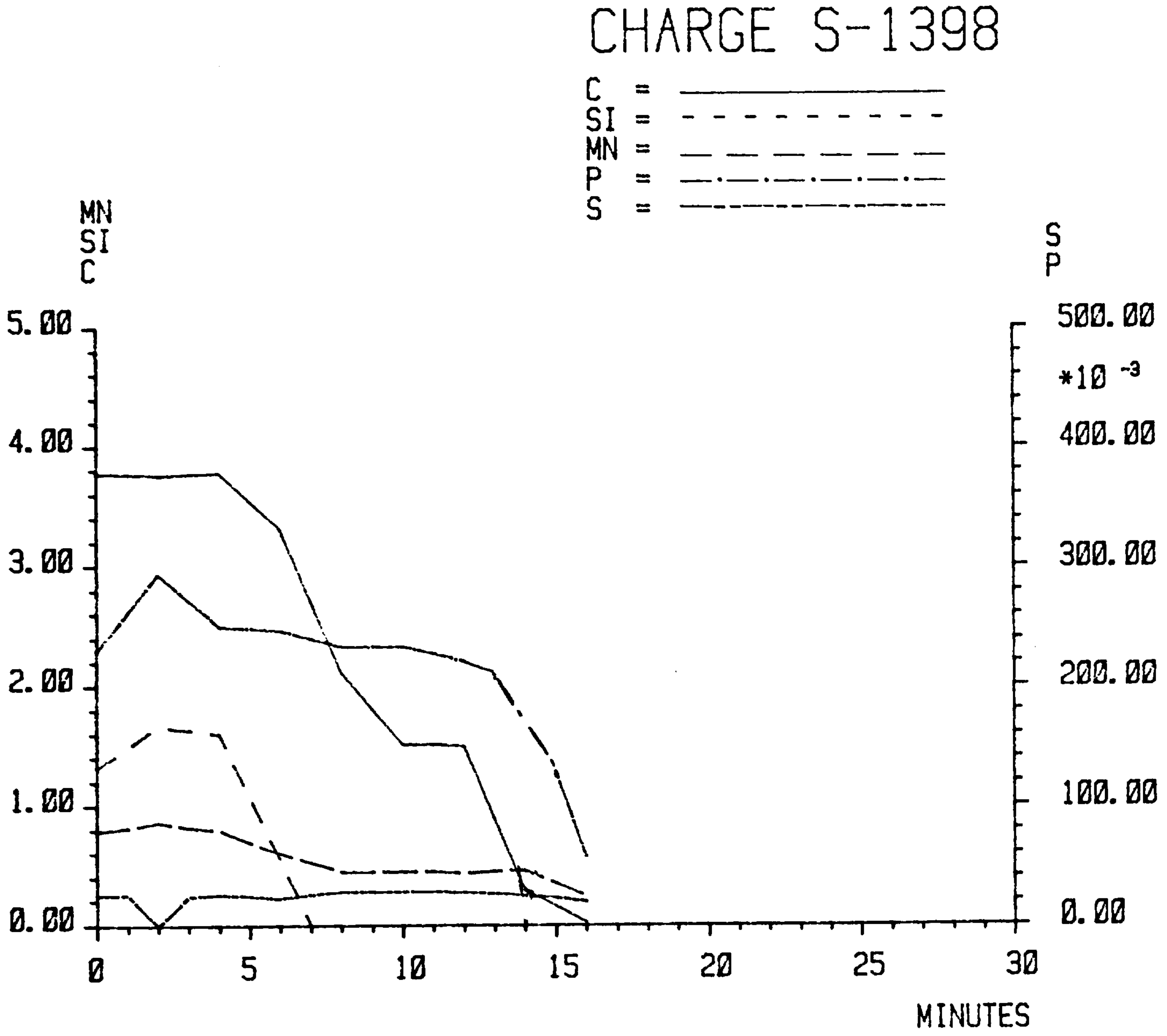
Appendix 16

CHARGE S-1410
YAAG =
FO2G =
FN2G =
KG/MIN
YAAG
M3N/MIN
FO2G
M3N/MIN
FN2G
30
25
20
15
10
5
0
20
15
10
5
0
2.0
1.5
1.0
0.5
0.0
0
5
10
15
20
25
30
35
40
45
MINUTES

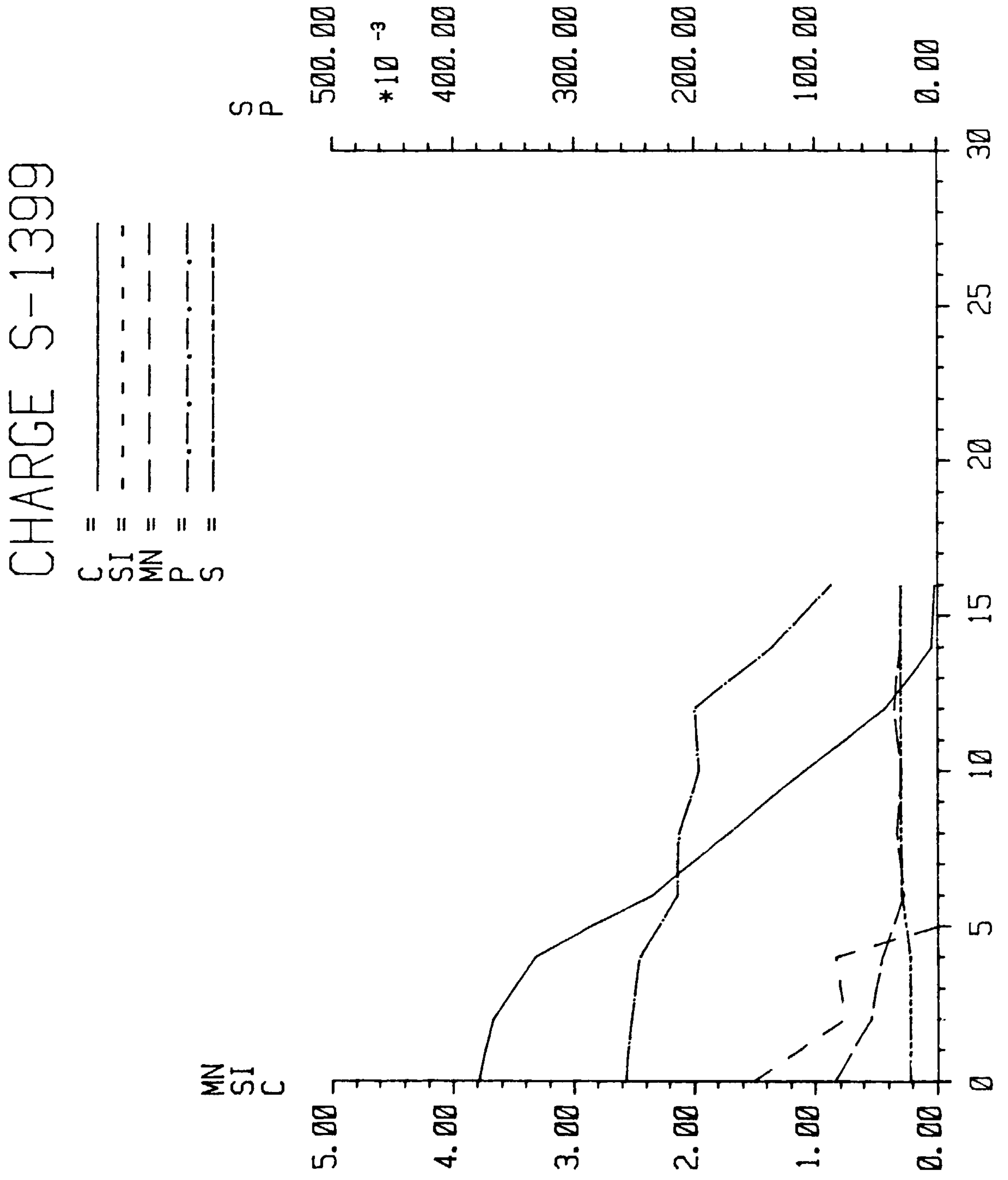
Appendix 17

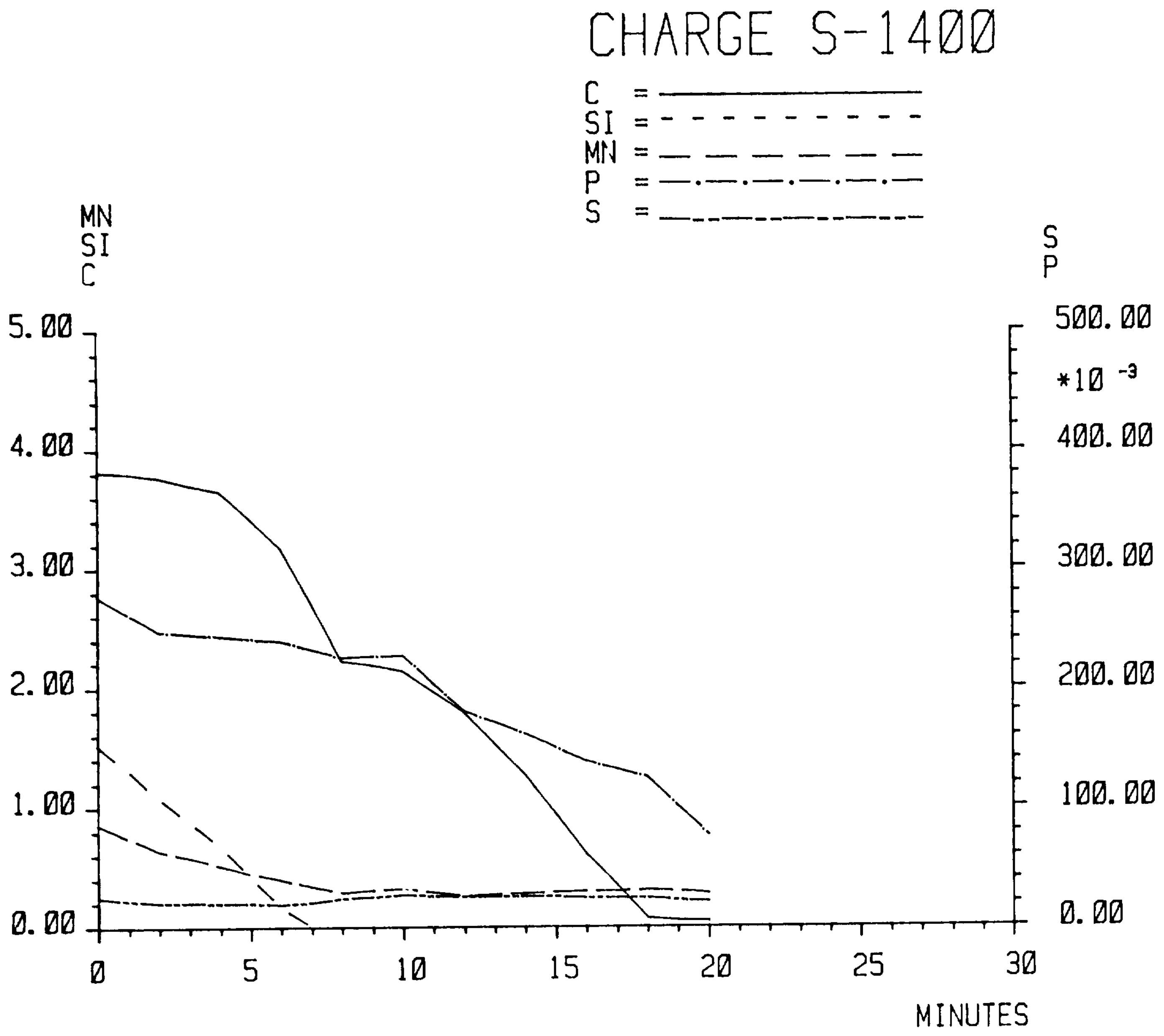

CHARGE S-1411
YAAG = ————
FO2G = - - - - -
FN2G = —·—·—
KG/MIN
YAAG
30
25
20
15
10
5
0
0
5
10
15
20
25
30
35
40
45
MINUTES
M3N/MIN
FO2G
20
15
10
5
0
M3N/MIN
FN2G
2.0
1.5
1.0
0.5
0.0


CHARGE S-1412
YAAG =
FO2G =
FN2G =
30
KG/MIN
YAAG
25
20
15
10
5
0
M3N/MIN
FO2G
M3N/MIN
FN2G
20
15
10
5
0
2.0
1.5
1.0
0.5
0.0
0
5
10
15
20
25
30
35
40
45
MINUTES

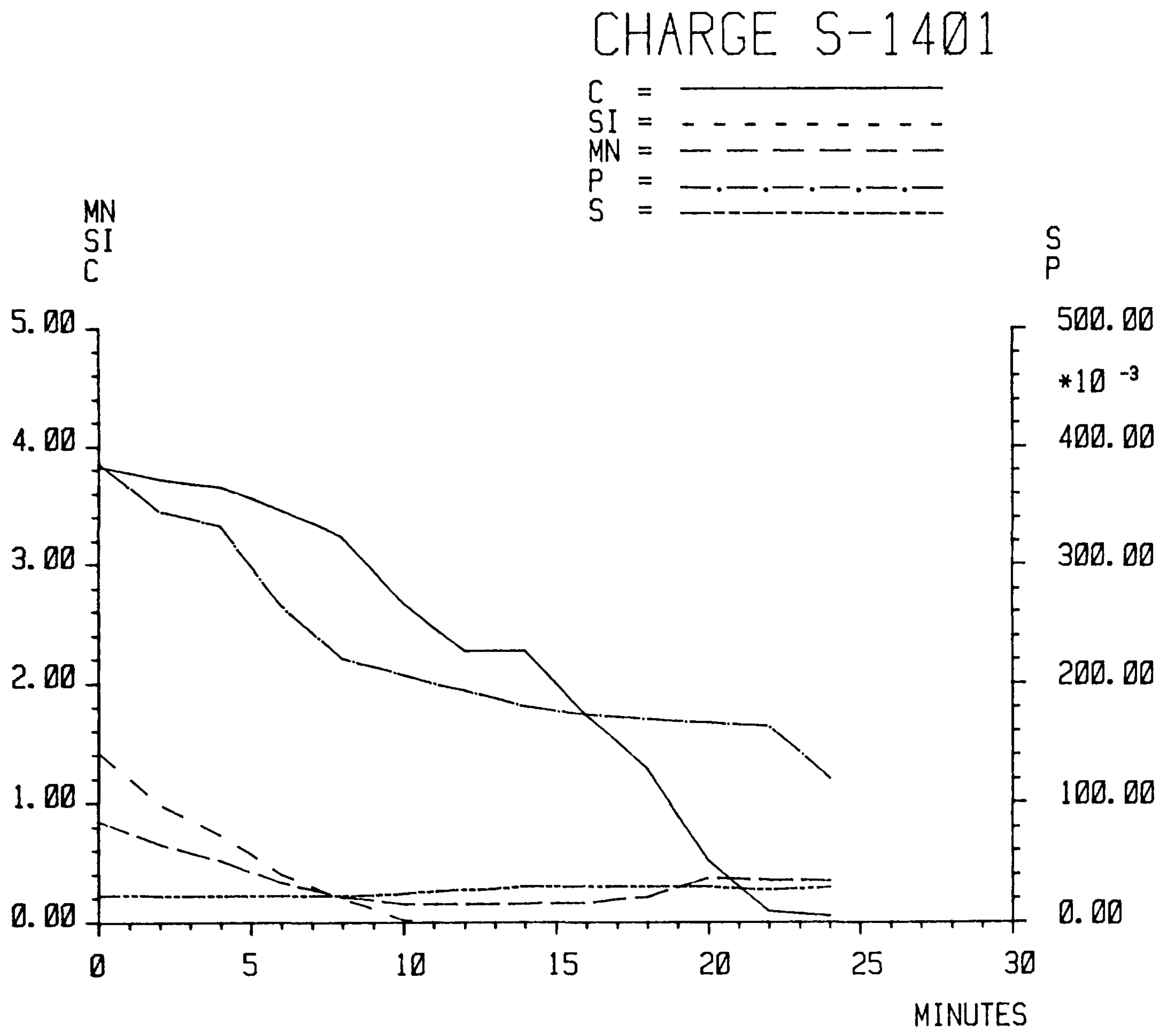

CHARGE S-1398
C =
SI =
MN =
P =
S =
MN
SI
C
5.00
4.00
3.00
2.00
1.00
0.00
S
P
500.00
*10 -3
400.00
300.00
200.00
100.00
0.00
0
5
10
15
20
25
30
MINUTES

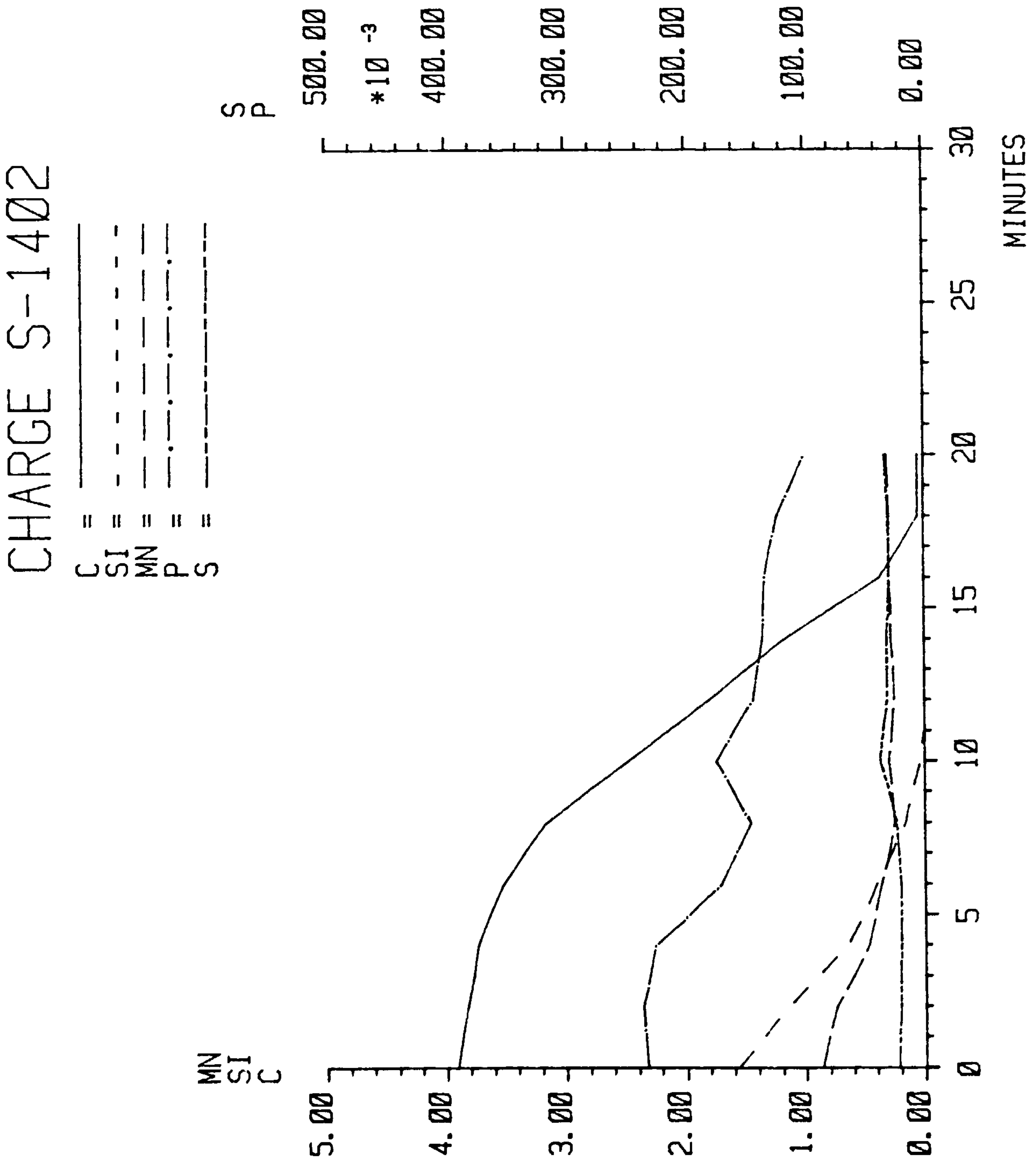
Appendix 21


CHARGE S-1399
C = ————
SI = - - - - -
MN = — — — —
P = —·—·—
S = —··—··—
MN
SI
C
5.00
4.00
3.00
2.00
1.00
0.00
S
P
500.00
*10 -3
400.00
300.00
200.00
100.00
0.00
0
5
10
15
20
25
30
MINUTES

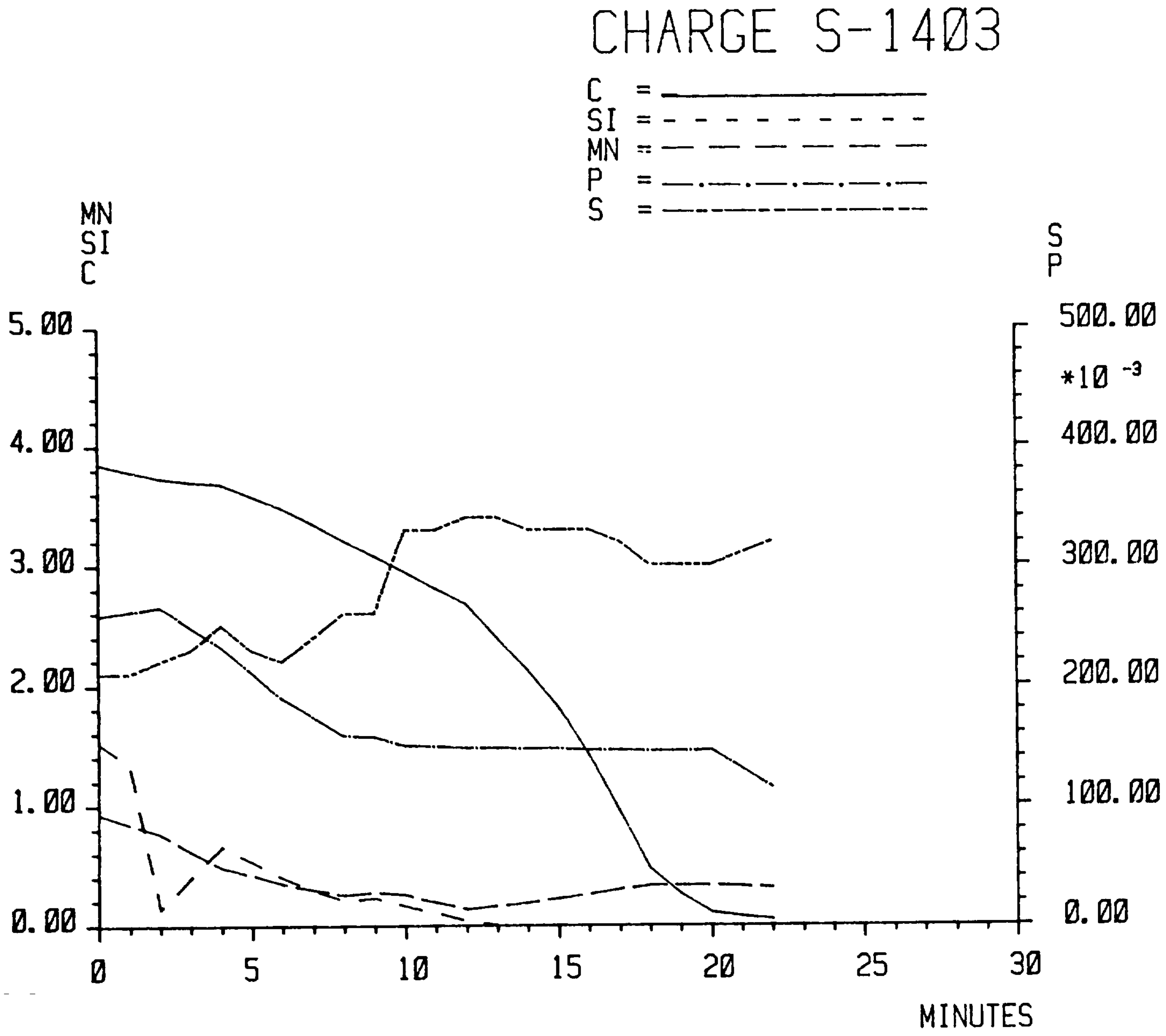

CHARGE S-1400
C =
SI =
MN =
P =
S =
MN
SI
C
5.00
4.00
3.00
2.00
1.00
0.00
S
P
500.00
*10 -3
400.00
300.00
200.00
100.00
0.00
0
5
10
15
20
25
30
MINUTES

Appendix 23

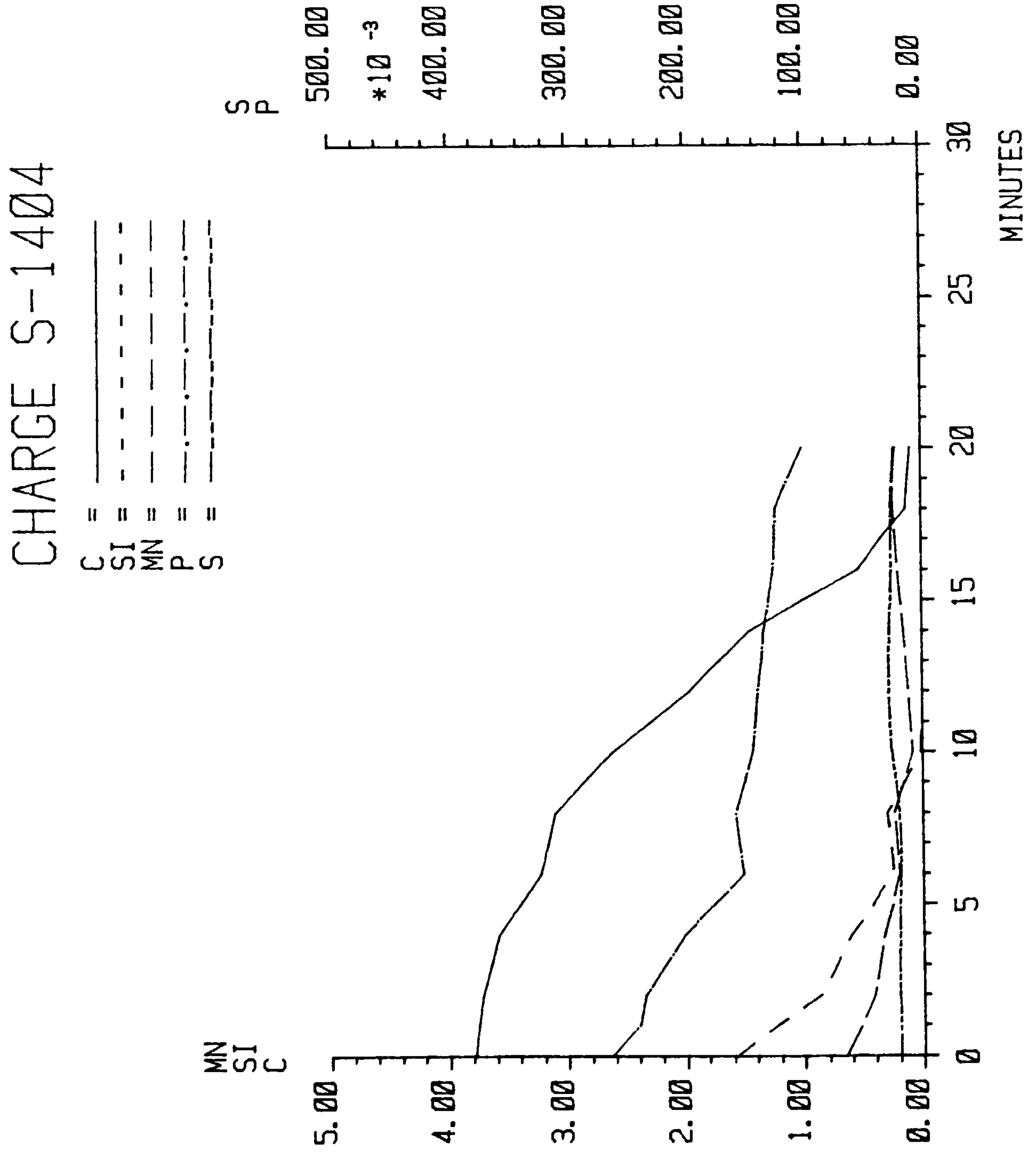

CHARGE S-1401
C =
SI =
MN =
P =
S =
MN
SI
C
5.00
4.00
3.00
2.00
1.00
0.00
S
P
500.00
*10 -3
400.00
300.00
200.00
100.00
0.00
0
5
10
15
20
25
30
MINUTES

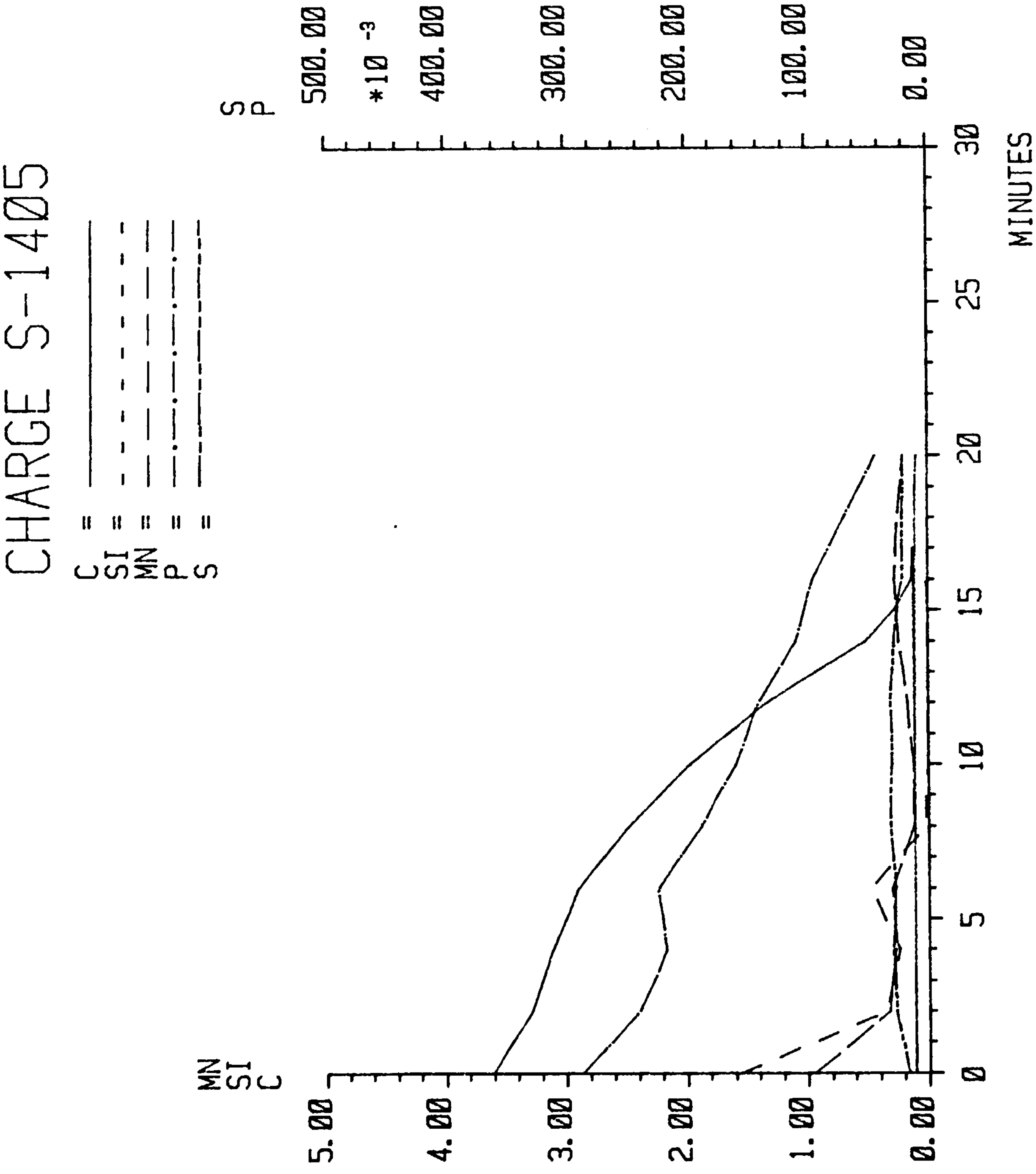

CHARGE S-1402
C =
SI =
MN =
P =
S =
MN
SI
C
5.00
4.00
3.00
2.00
1.00
0.00
S
P
500.00
*10 -3
400.00
300.00
200.00
100.00
0.00
0
5
10
15
20
25
30
MINUTES

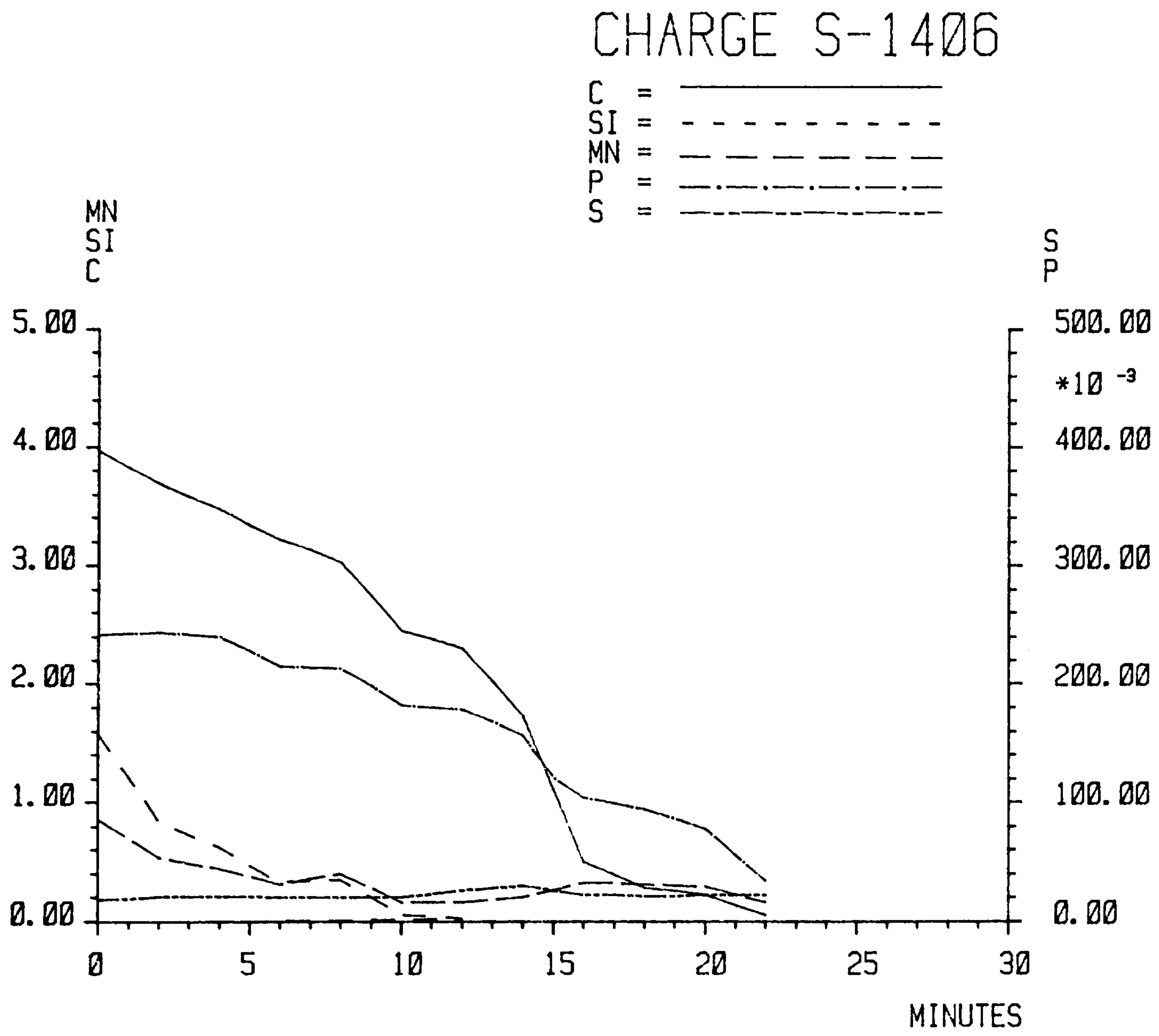
Appendix 25


CHARGE S-1403
C =
SI =
MN =
P =
S =
MN
SI
C
5.00
4.00
3.00
2.00
1.00
0.00
S
P
500.00
*10 -3
400.00
300.00
200.00
100.00
0.00
0
5
10
15
20
25
30
MINUTES

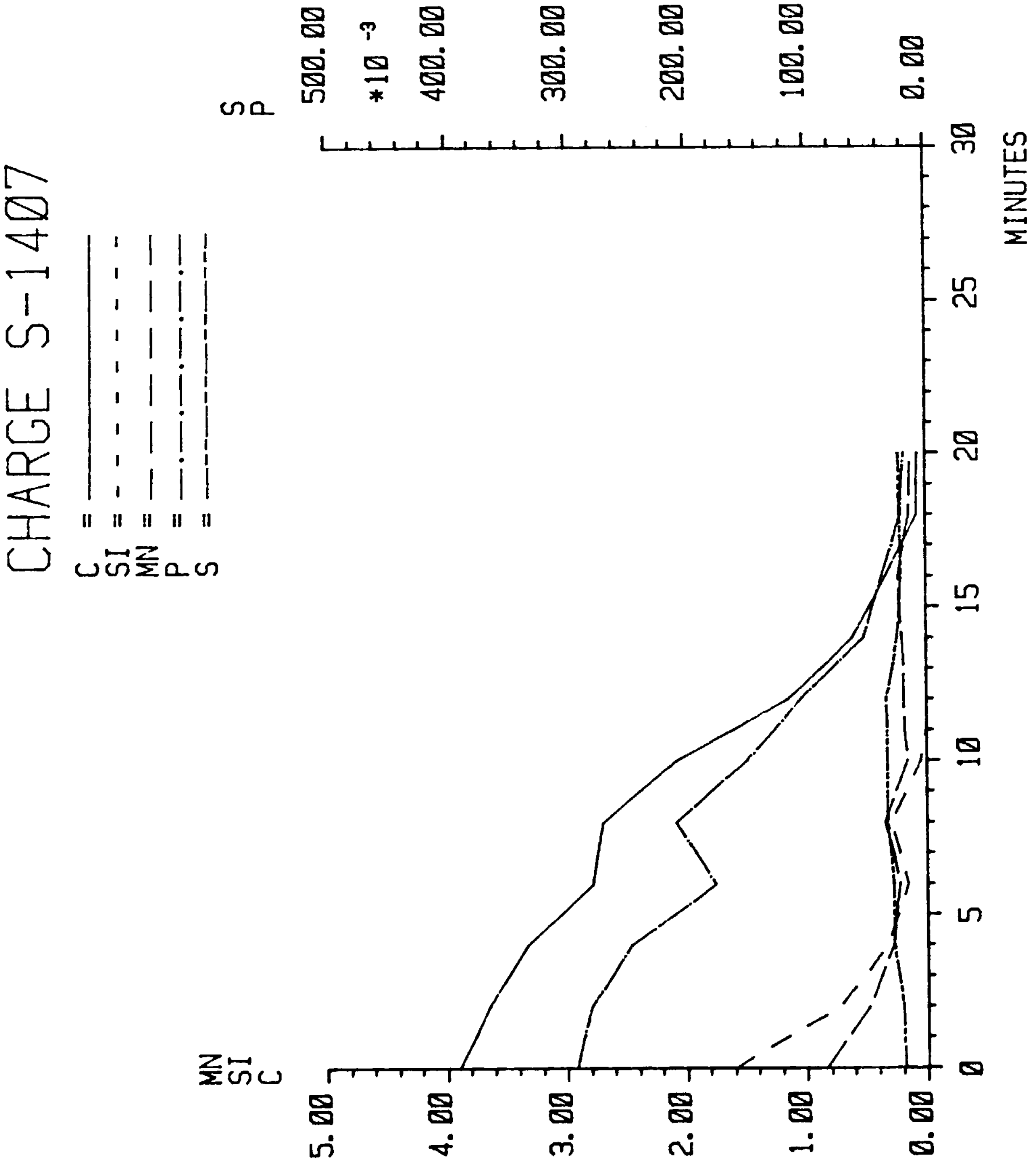
Appendix 26


CHARGE S-1404
C =
SI =
MN =
P =
S =
MN
SI
C
5.00
4.00
3.00
2.00
1.00
0.00
S
P
500.00
*10 -3
400.00
300.00
200.00
100.00
0.00
0
5
10
15
20
25
30
MINUTES

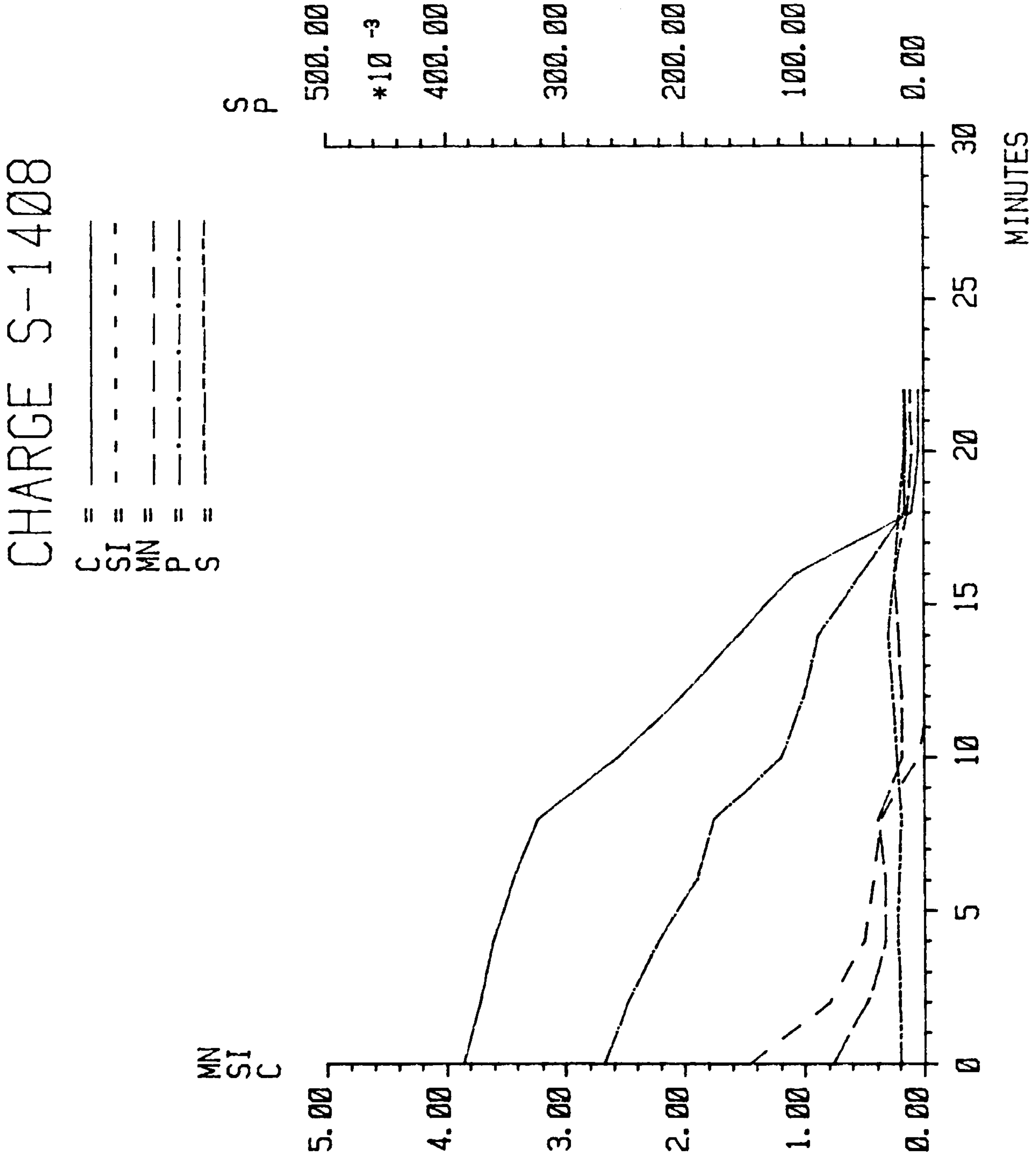

CHARGE S-1405
C =
SI =
MN =
P =
S =
MN
SI
C
5.00
4.00
3.00
2.00
1.00
0.00
S
P
500.00
*10 -3
400.00
300.00
200.00
100.00
0.00
0
5
10
15
20
25
30
MINUTES

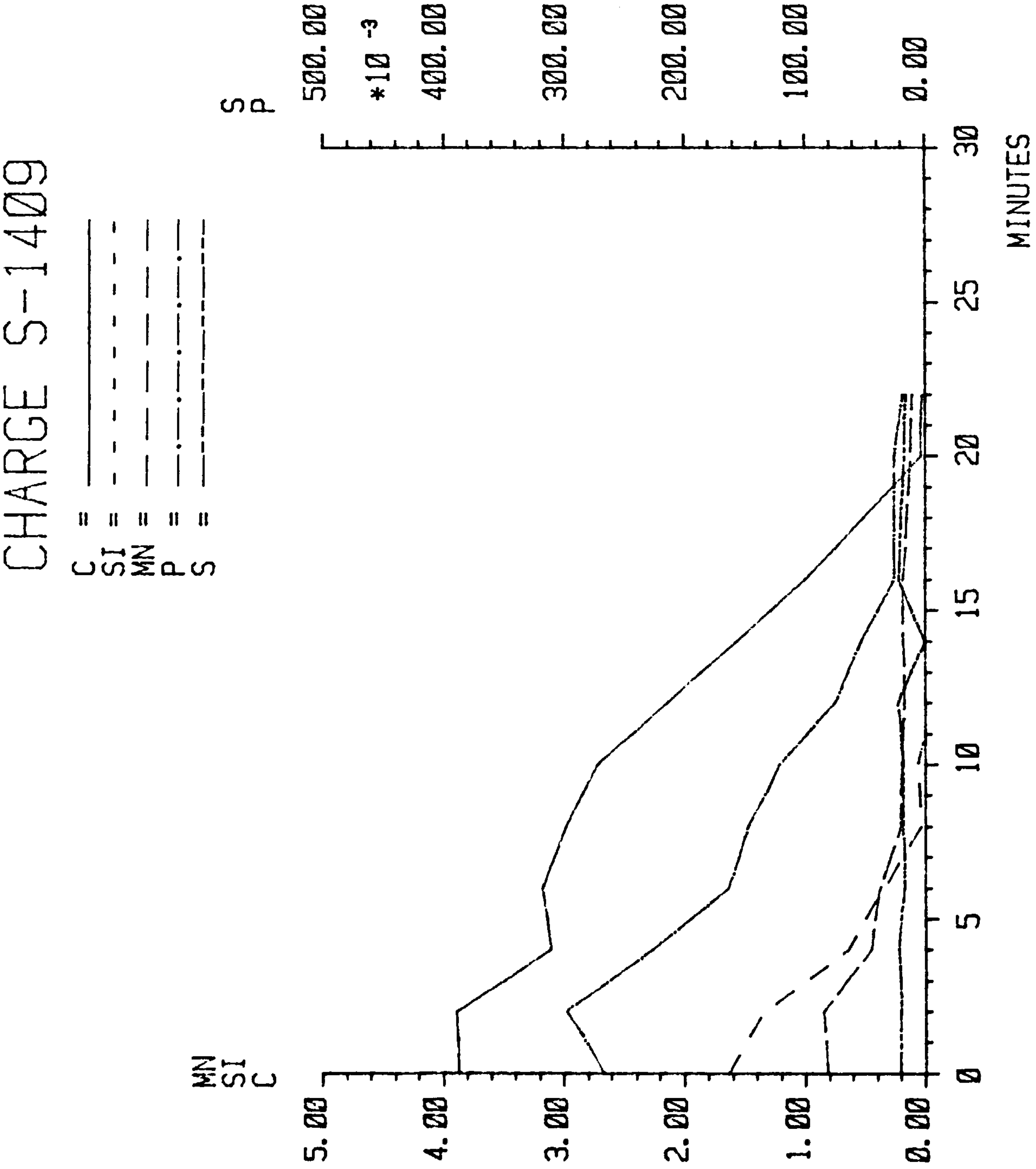

CHARGE S-1406
C =
SI =
MN =
P =
S =
MN
SI
C
5.00
4.00
3.00
2.00
1.00
0.00
S
P
500.00
*10 -3
400.00
300.00
200.00
100.00
0.00
0
5
10
15
20
25
30
MINUTES

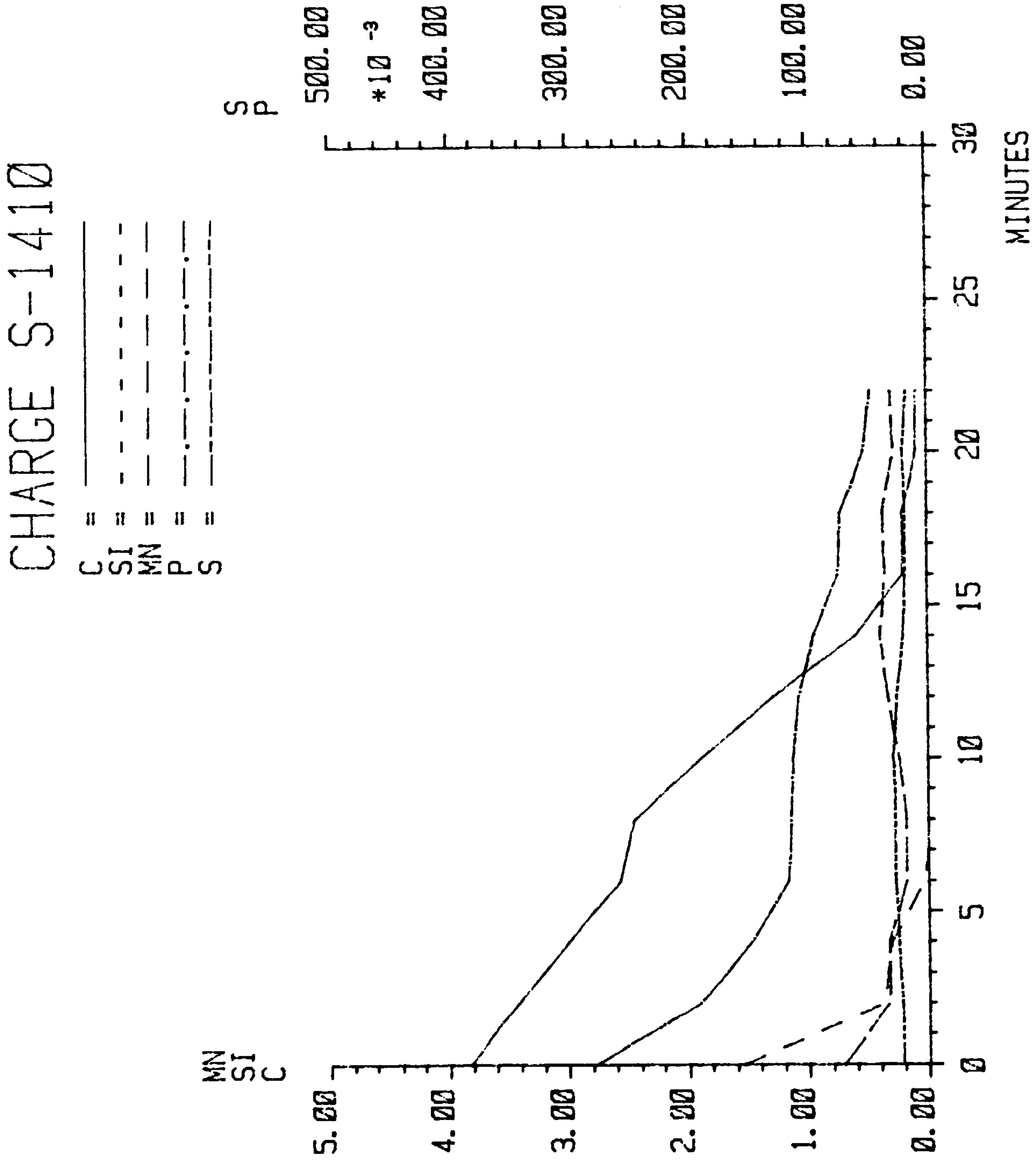
Appendix 29


CHARGE S-1407
C =
SI =
MN =
P =
S =
MN
SI
C
5.00
4.00
3.00
2.00
1.00
0.00
S
P
500.00
*10 -3
400.00
300.00
200.00
100.00
0.00
0
5
10
15
20
25
30
MINUTES

Appendix 30


CHARGE S-1408
C =
SI =
MN =
P =
S =
MN
SI
C
5.00
4.00
3.00
2.00
1.00
0.00
S
P
500.00
*10 -3
400.00
300.00
200.00
100.00
0.00
0
5
10
15
20
25
30
MINUTES


CHARGE S-1409
C =
SI =
MN =
P =
S =
MN
SI
C
5.00
4.00
3.00
2.00
1.00
0.00
S
P
500.00
*10 -3
400.00
300.00
200.00
100.00
0.00
0
5
10
15
20
25
30
MINUTES


CHARGE S-1410
C =
SI =
MN =
P =
S =
MN
SI
C
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S
P
500.00
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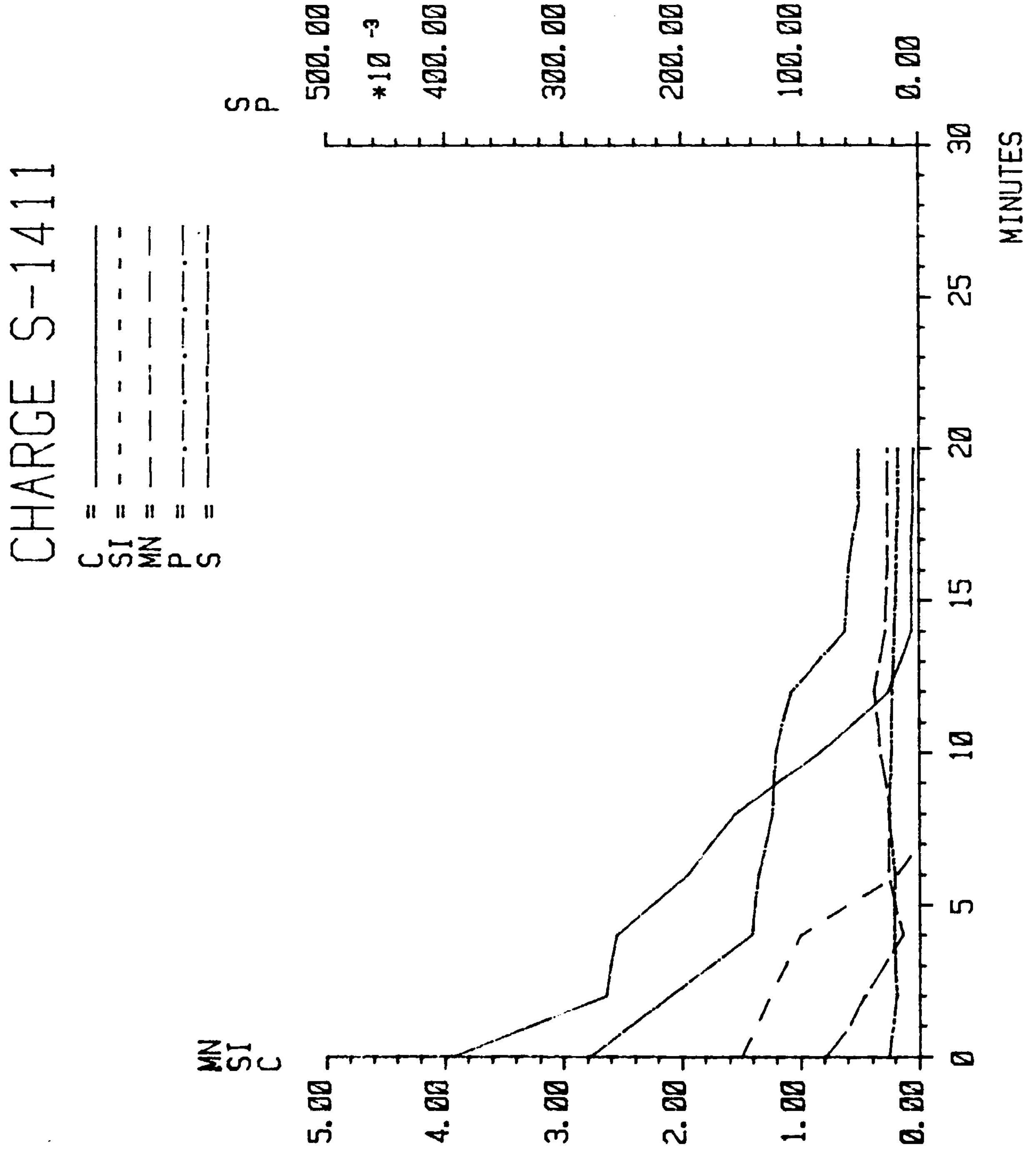
25
30
MINUTES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C
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S
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500.00
*10 -3
400.00
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100.00
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0
5
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15
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25
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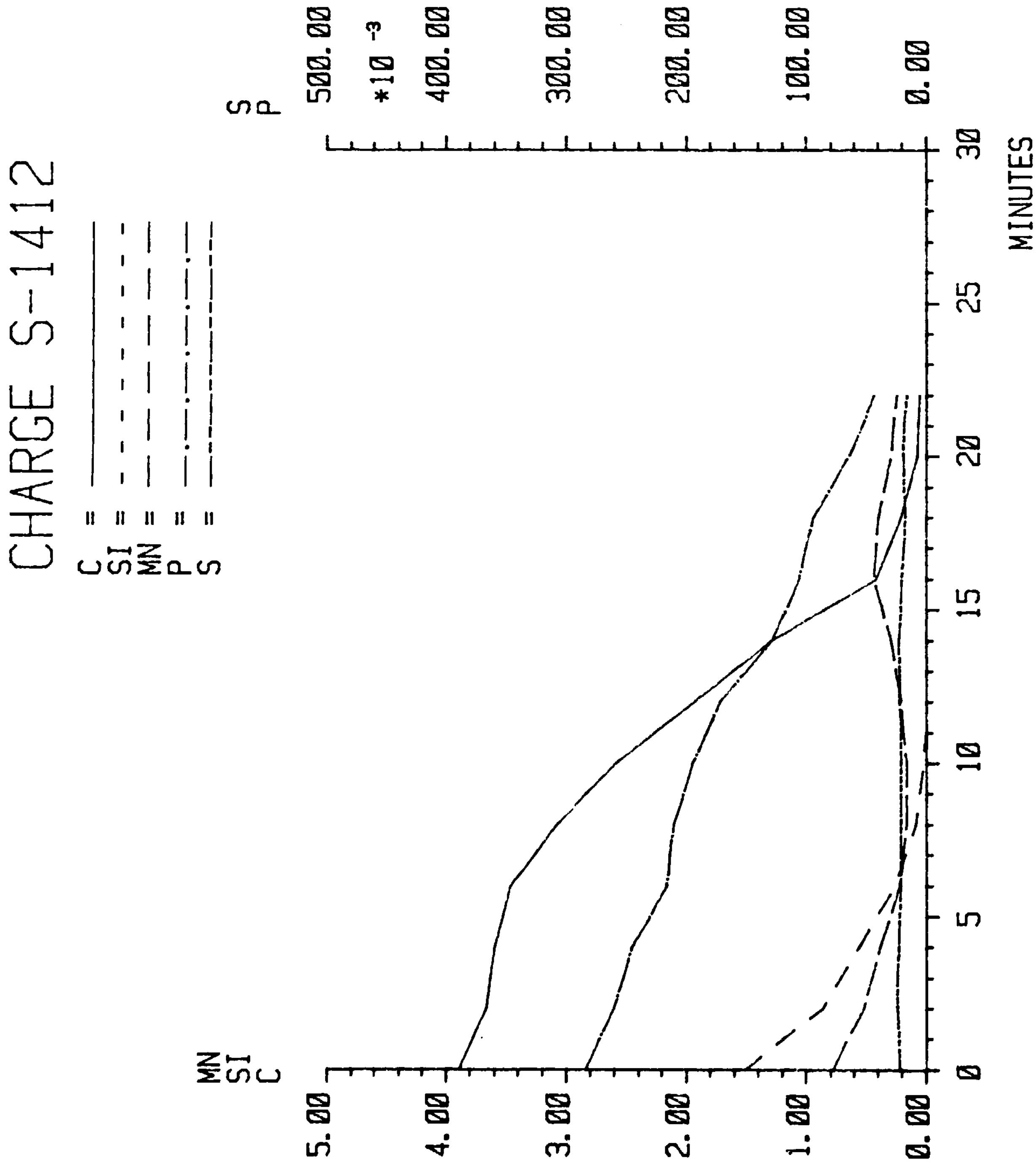
MINUTES

Appendix 34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P = —·—·—·—
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MN
SI
C
5.00
4.00
3.00
2.00
1.00
0.00
S
P
500.00
*10 -3
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200.00
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0.00
0
5
10
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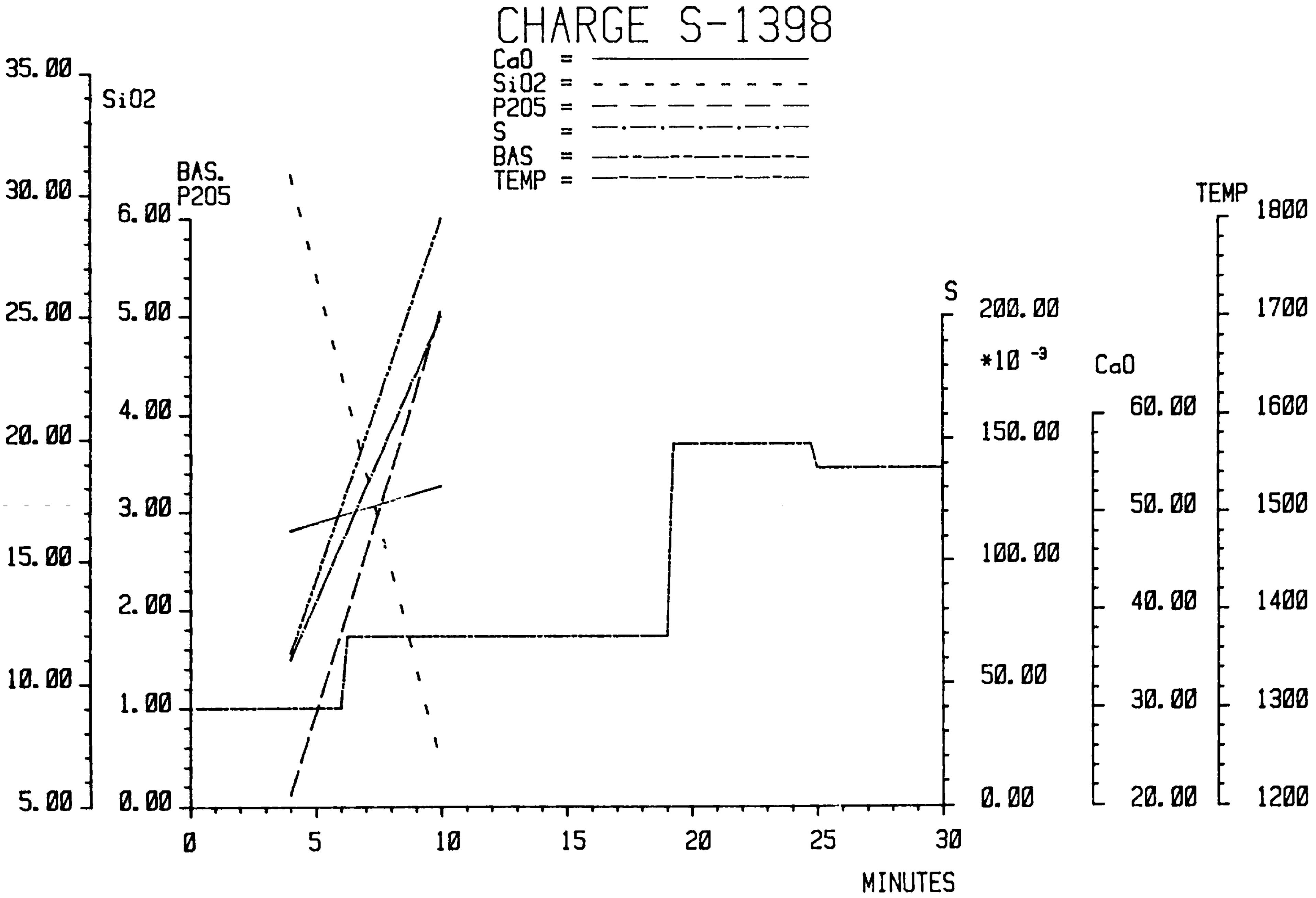
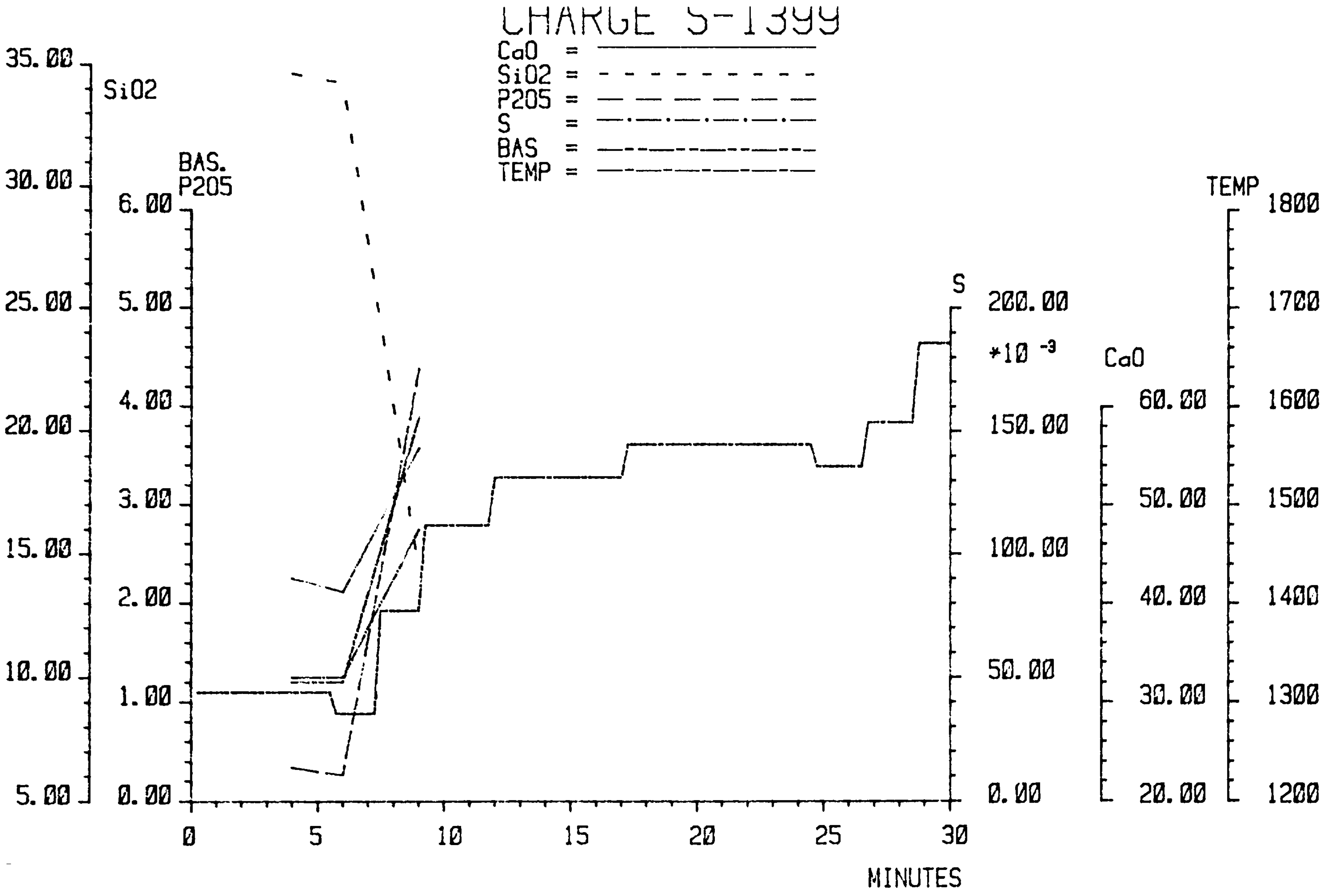
20
25
30
MINUTES



CHARGE S-1398

Appendix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BAS =
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20.00
15.00
10.00
5.00
BAS.
P2O5
6.00
5.00
4.00
3.00
2.00
1.00
0.00
0
5
10
15
20
25
30
MINUTES
S
200.00
*10 -3
150.00
100.00
50.00
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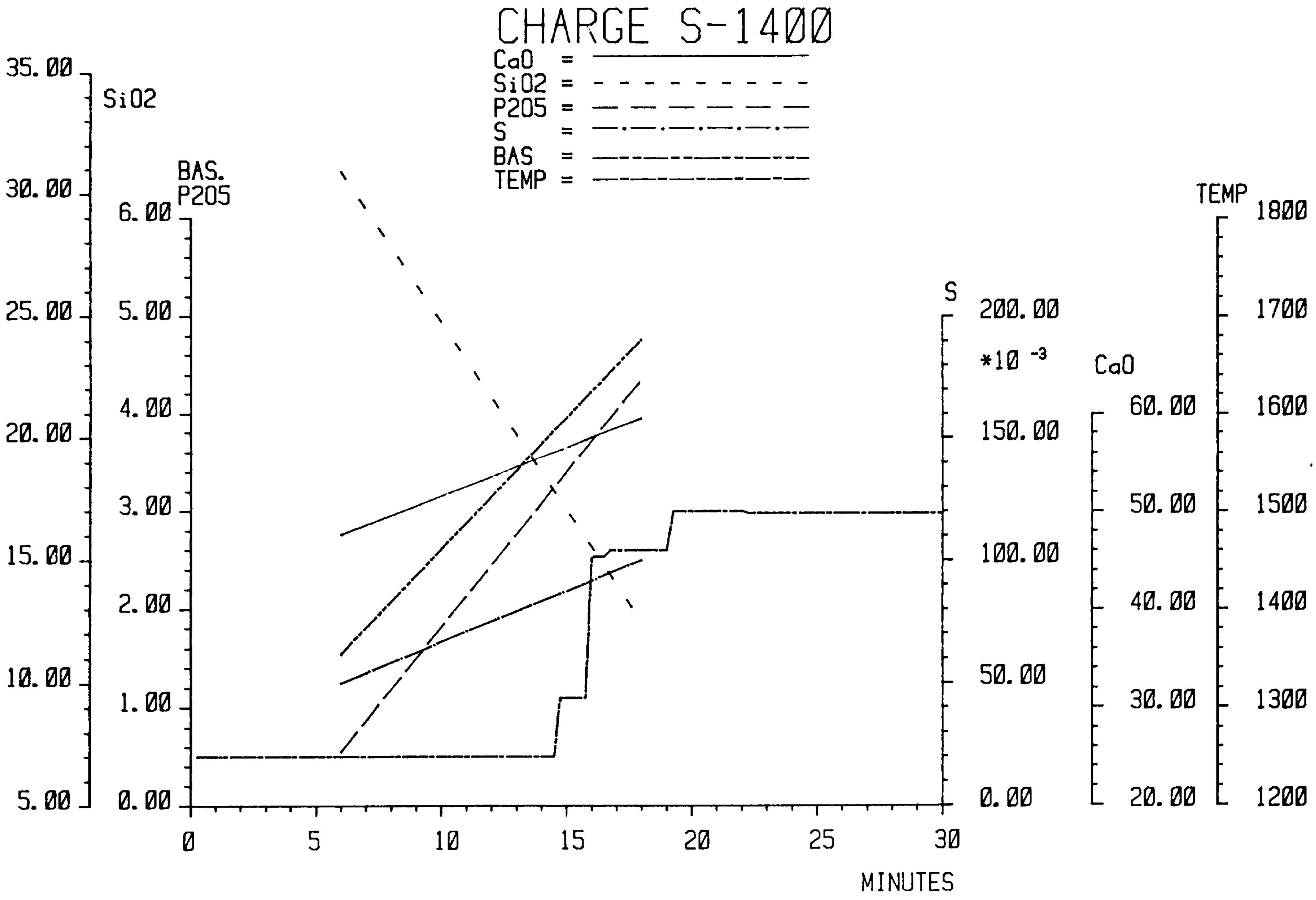
1300
1200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25.00
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15.00
10.00
5.00
BAS.
P2O5
6.00
5.00
4.00
3.00
2.00
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S
200.00
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150.00
100.00
50.00
0.00
CaO
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50.00
40.00
30.00
20.00
TEMP
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1500
1400
1300
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15
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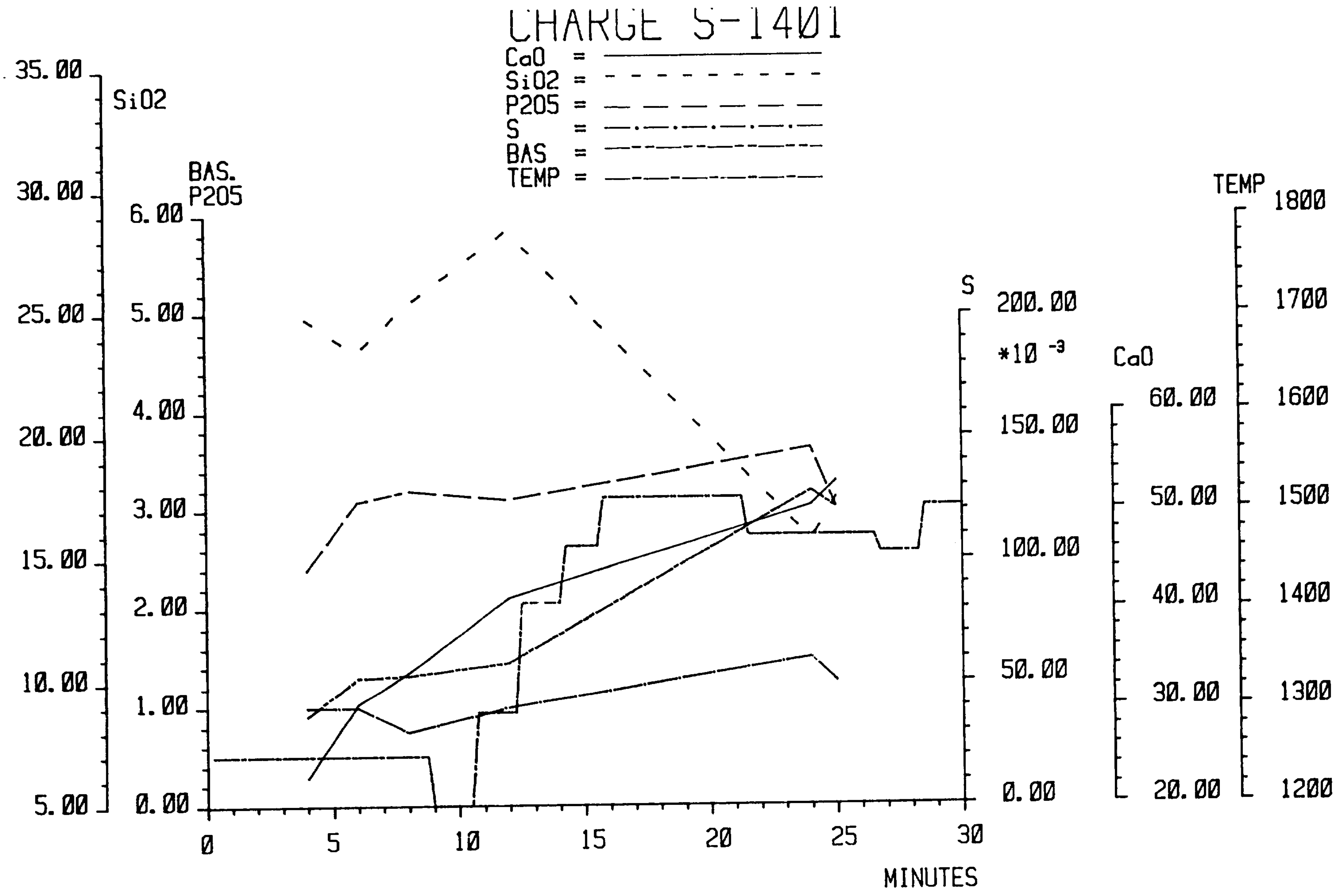
MINUTES

Appendix 37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15.00
10.00
5.00
BAS.
P2O5
6.00
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4.00
3.00
2.00
1.00
0.00
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200.00
*10 -3
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100.00
50.00
0.00
CaO
60.00
50.00
40.00
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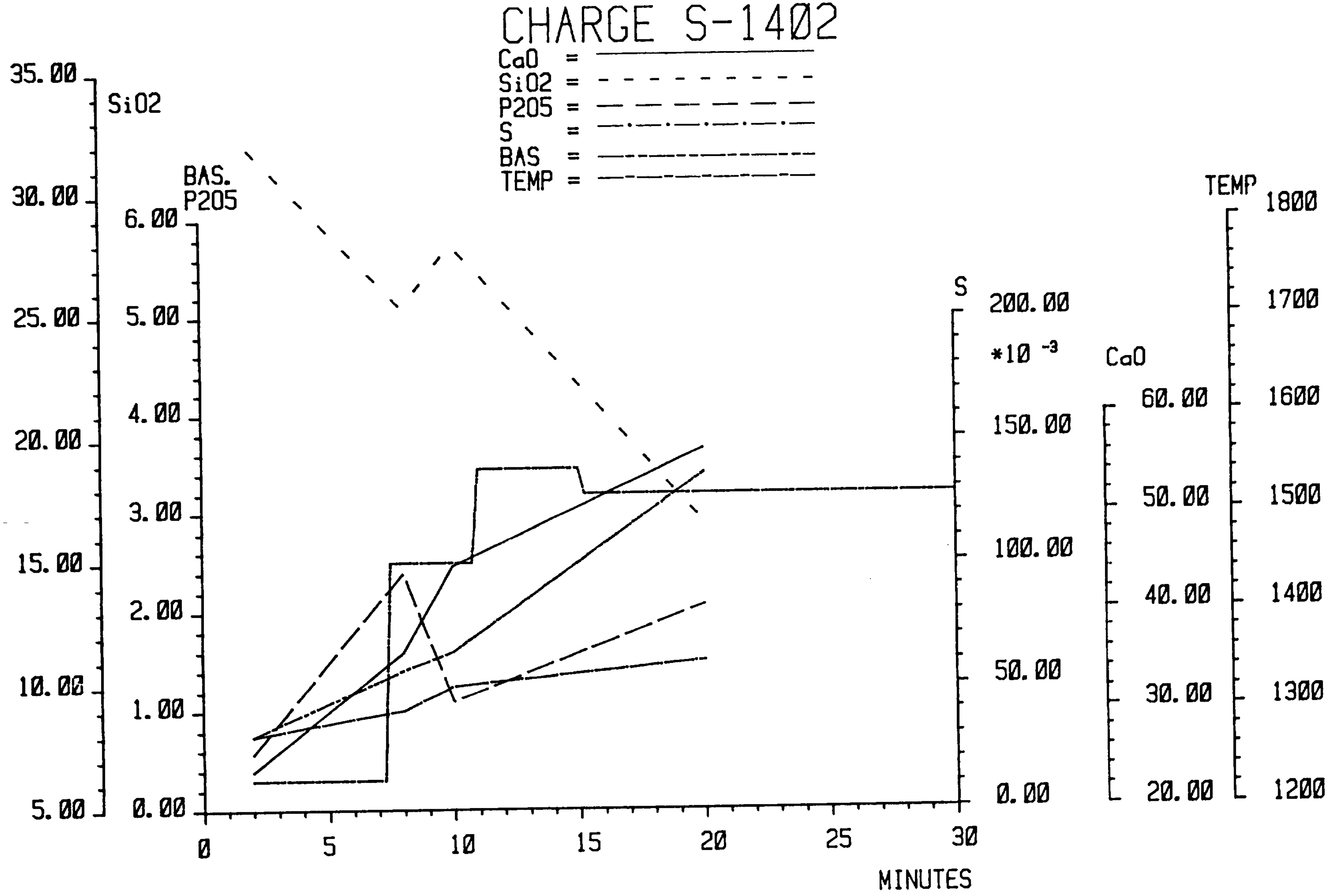
MINUTES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TEMP = ────────
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30.00
25.00
20.00
15.00
10.00
5.00
BAS.
P2O5
6.00
5.00
4.00
3.00
2.00
1.00
0.00
S
200.00
*10 -3
150.00
100.00
50.00
0.00
CaO
60.00
50.00
40.00
30.00
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TEMP
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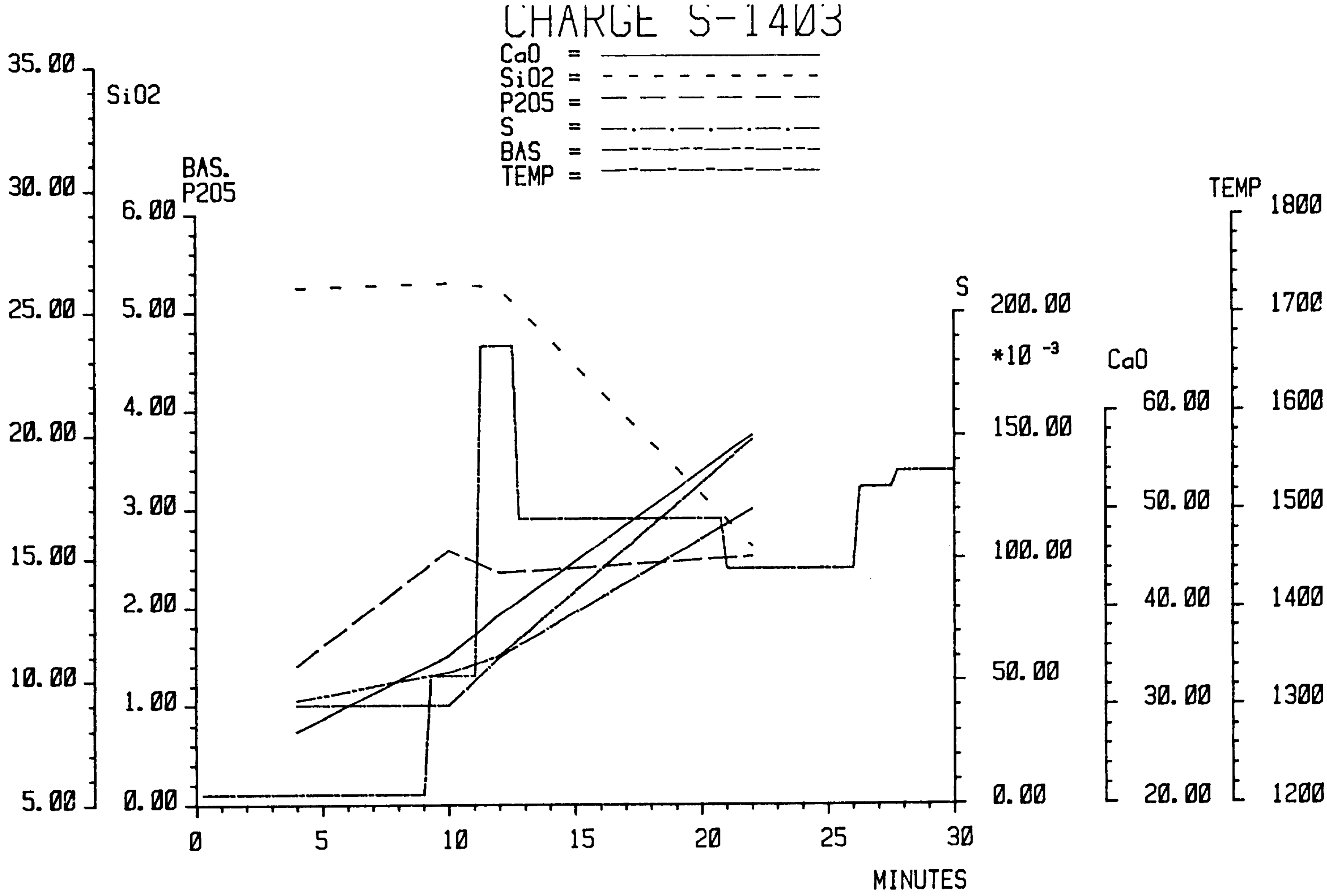
MINUTES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BAS.
P2O5
6.00
5.00
4.00
3.00
2.00
1.00
0.00
0
5
10
15
20
25
30
MINUTES
S
200.00
*10 -3
150.00
100.00
50.00
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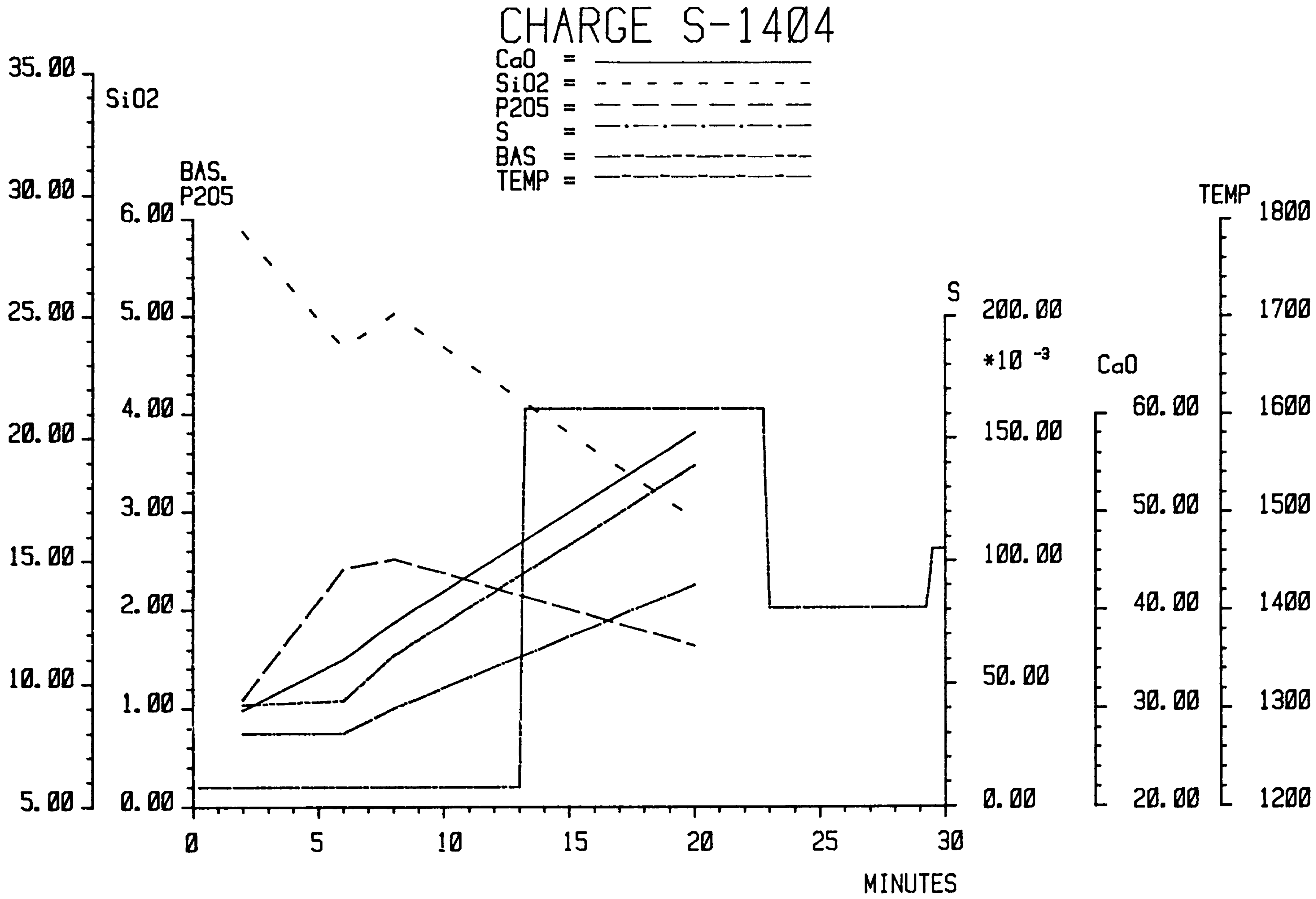
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BAS.
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CaO
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40.00
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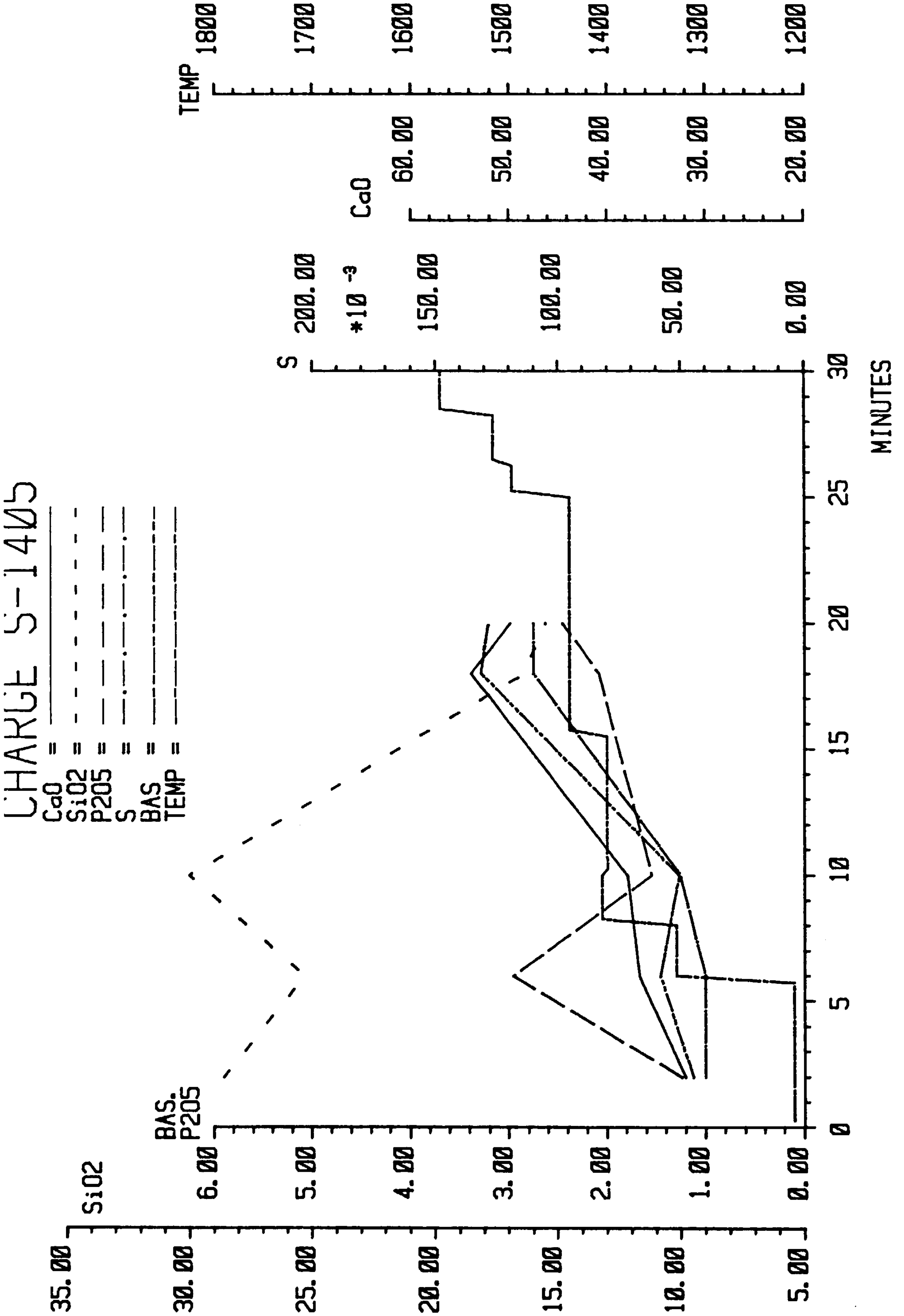
MINUTES

Appendix 41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50.00
40.00
30.00
20.00
S
200.00
*10 -3
150.00
100.00
50.00
0.00
MINUTES
0
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15
20
25
30
BAS.
P2O5
6.00
5.00
4.00
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1.00
0.00
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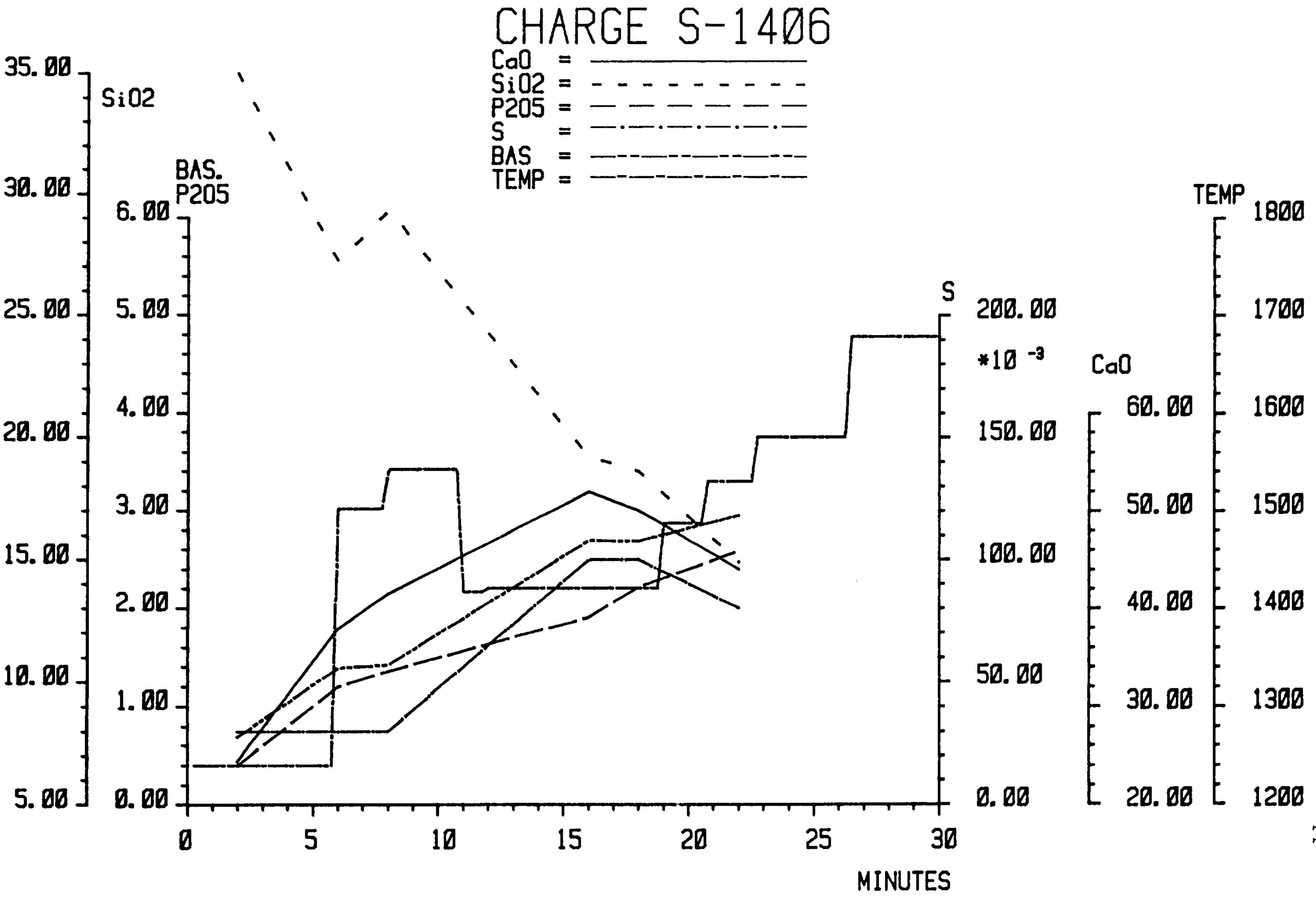
10.00
5.00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BAS.
P205
6.00
5.00
4.00
3.00
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0.00
0
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10
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MINUTES
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200.00
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100.00
50.00
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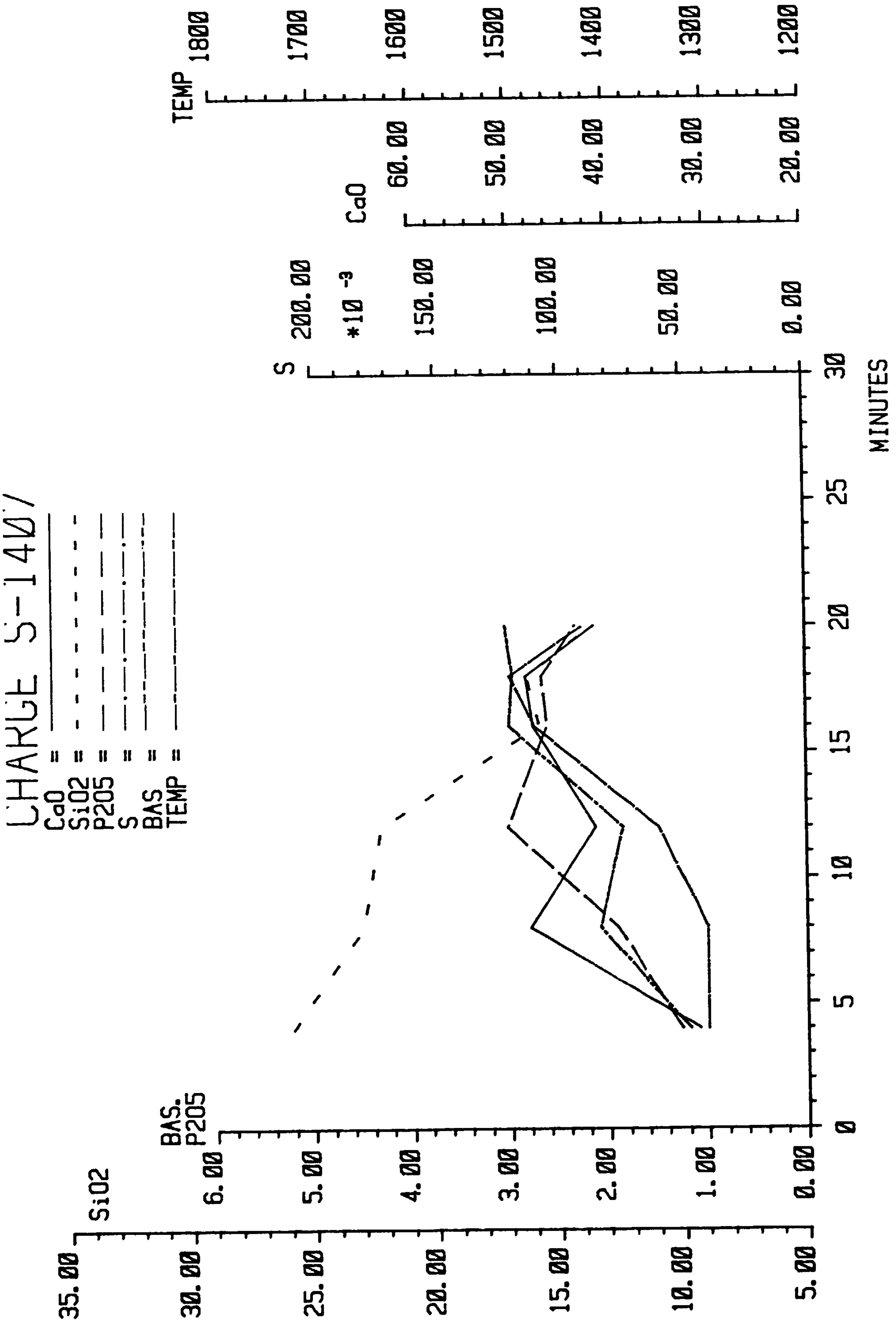
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15.00
10.00
5.00
BAS.
P2O5
6.00
5.00
4.00
3.00
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MINUTES
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200.00
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150.00
100.00
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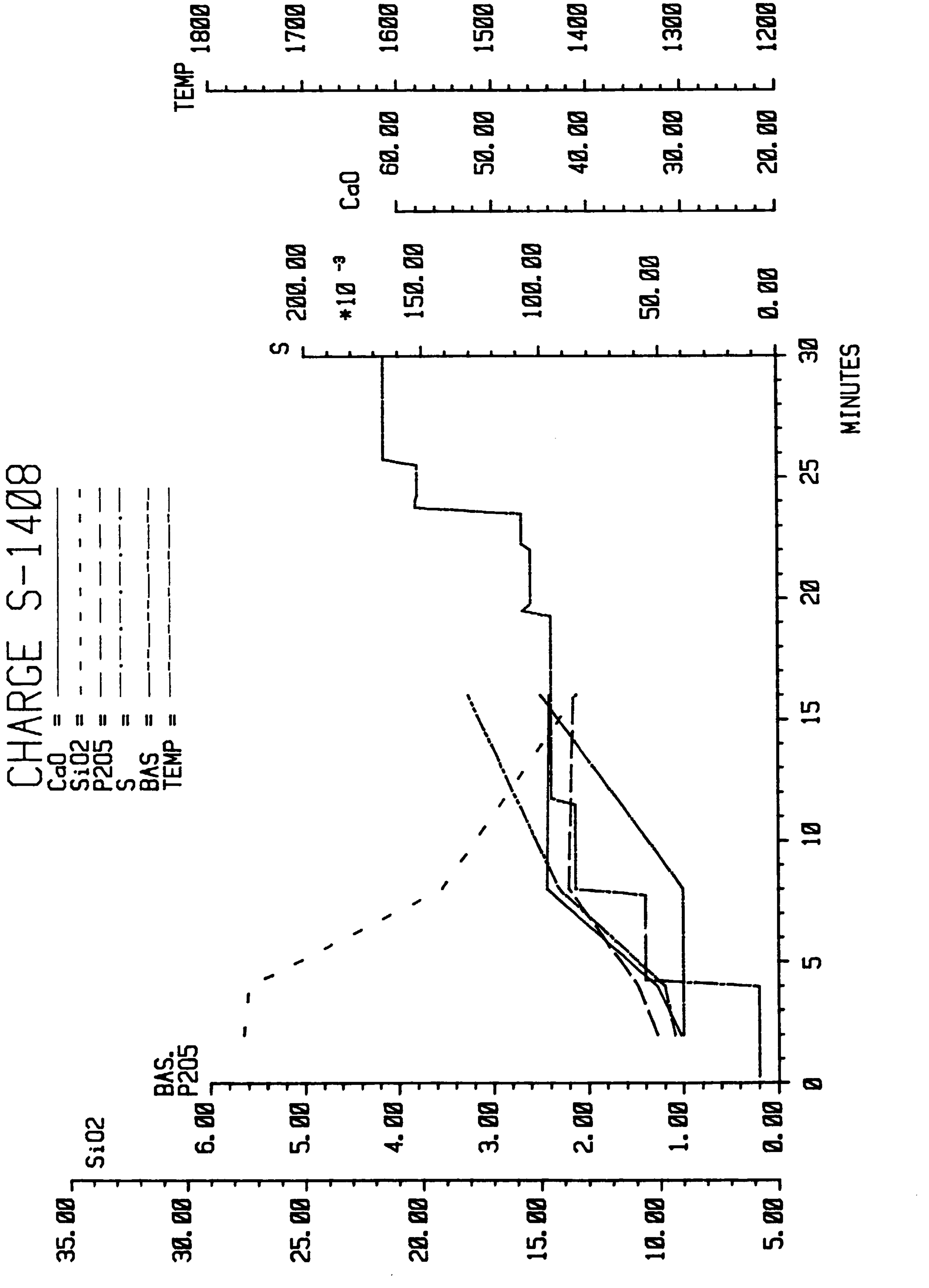
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40.00
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20.00
S
200.00
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0.00
MINUTES
0
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30
BAS.
P2O5
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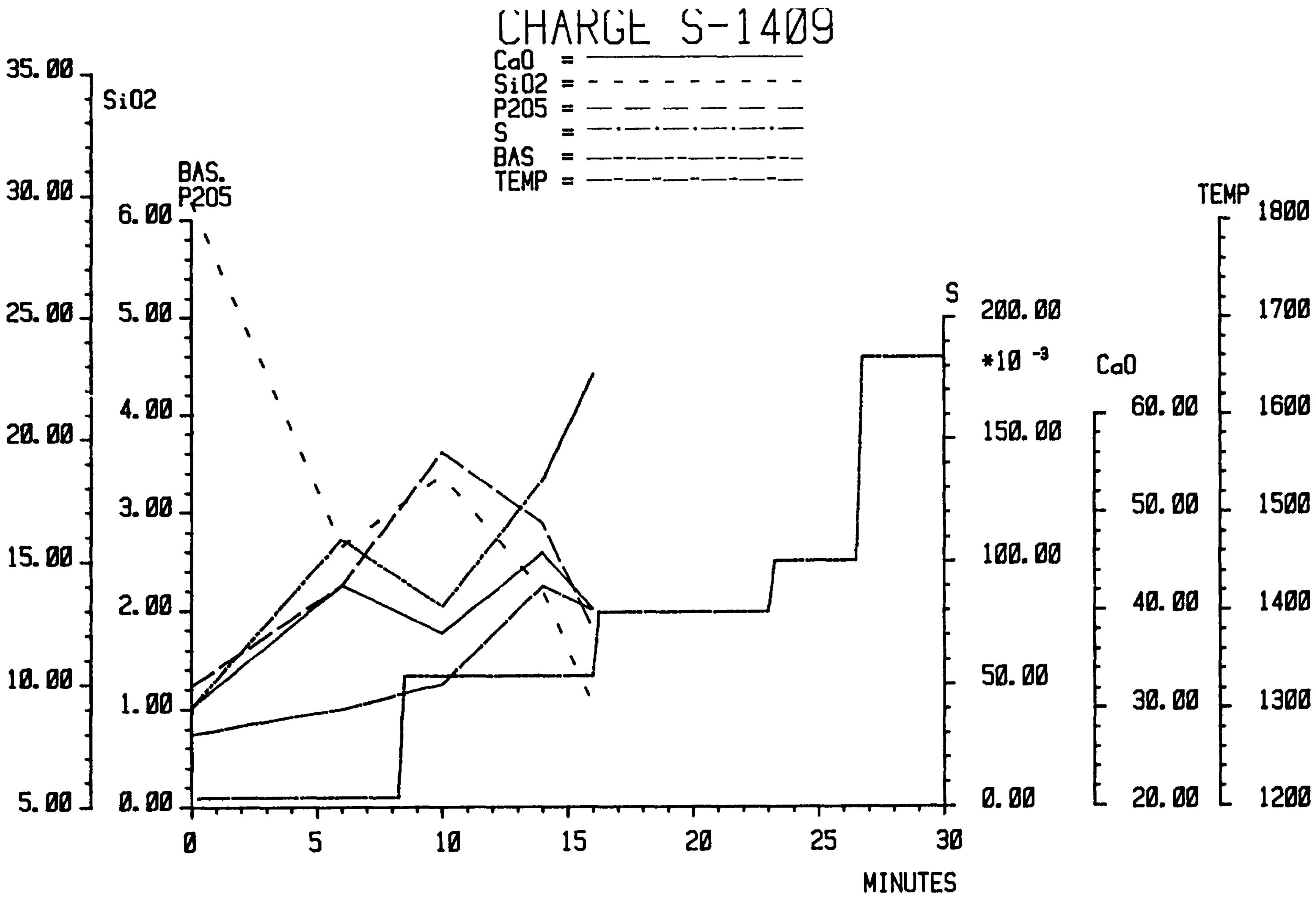
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5.00
BAS.
P2O5
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5.00
4.00
3.00
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0.00
0
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10
15
20
25
30
MINUTES
S
200.00
*10 -3
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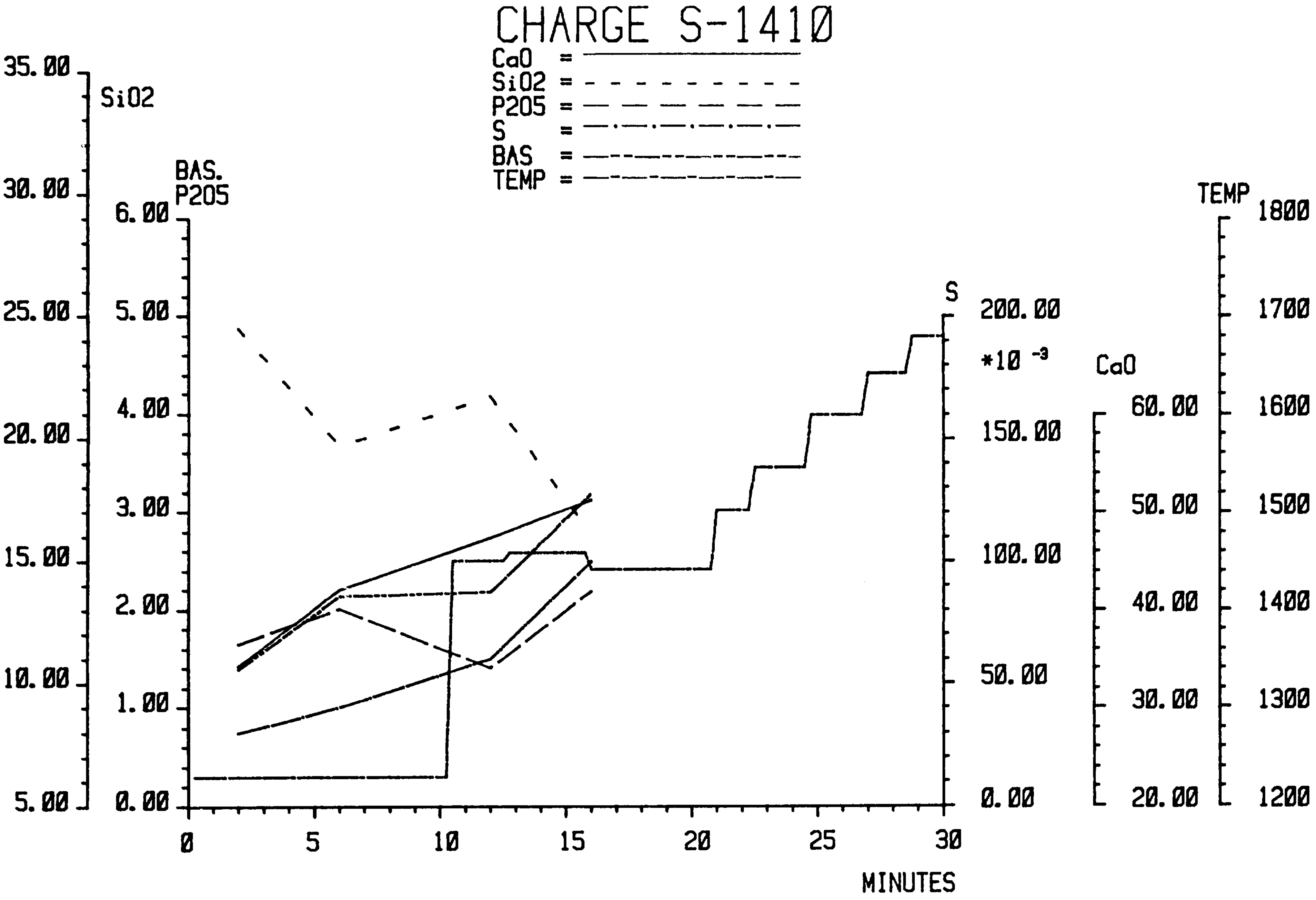
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MINUTES
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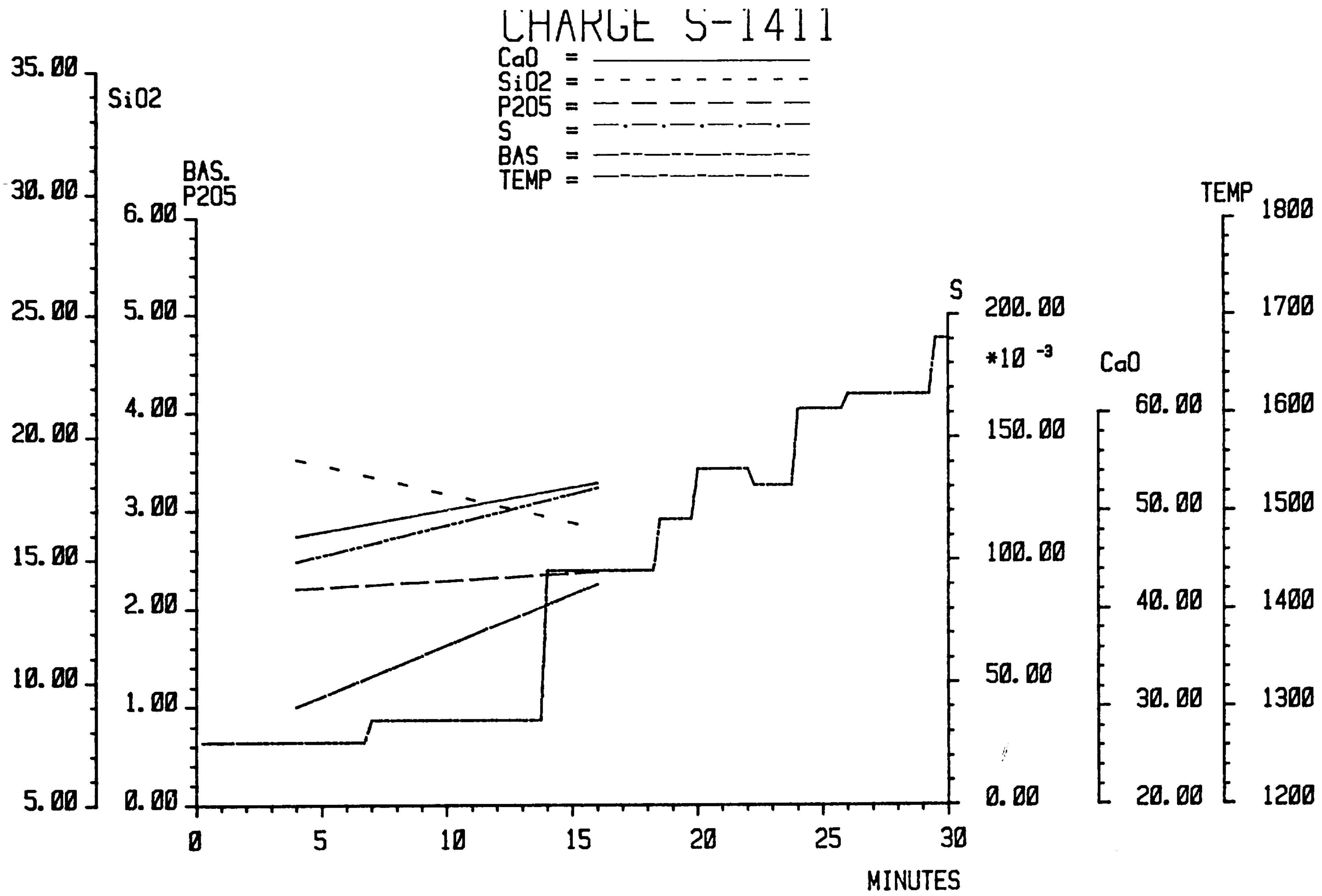
Appendix 48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MINUTES
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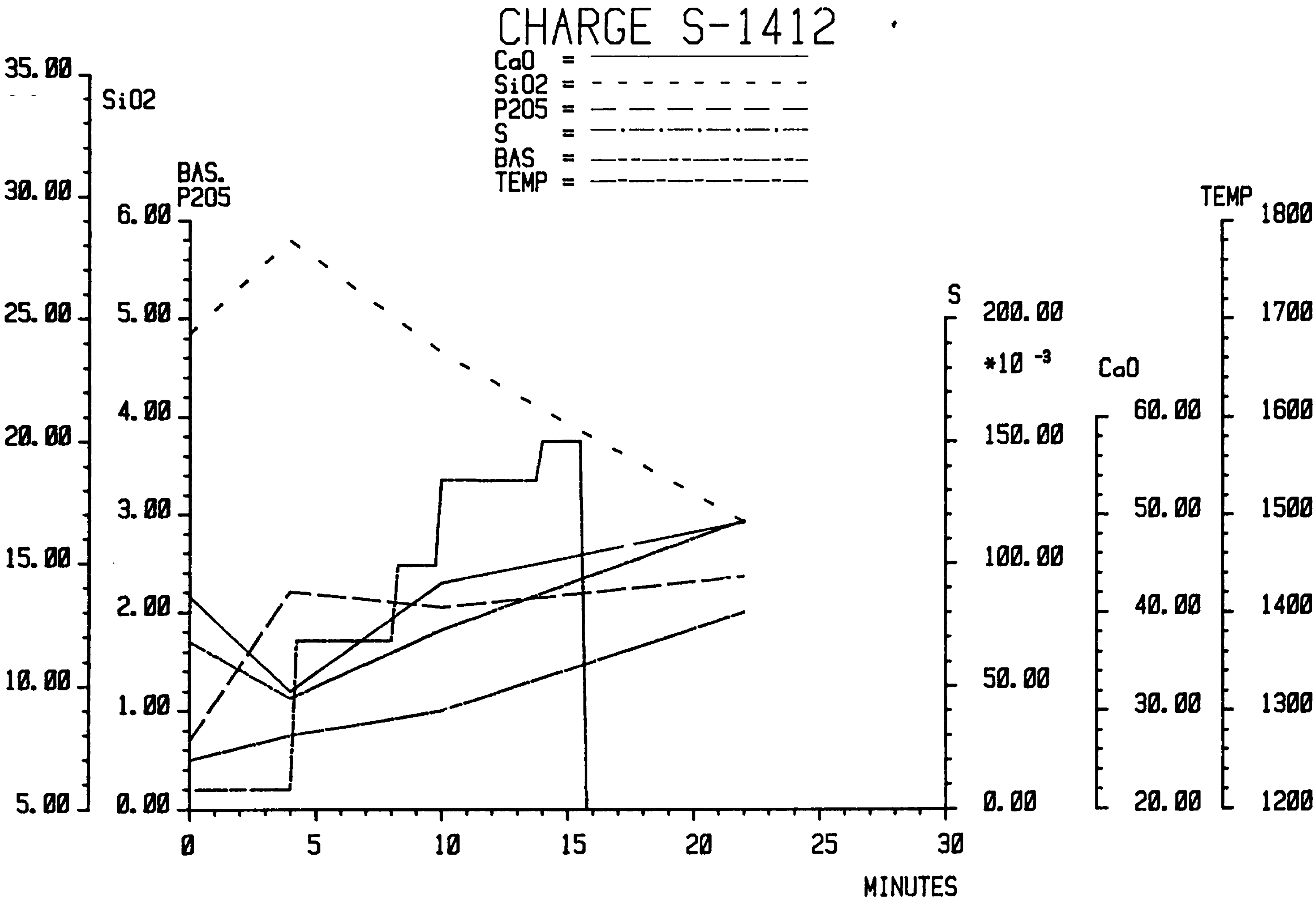
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P205
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200.00
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50.00
0.00
CaO
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50.00
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MINUTES

Appendix 9

MEFOS
METALLURGISKA
FORSKNINGSSTATIONEN

Forskningsuppdrag	Konto	Datum	Reg nr
	4449	1985-05-07	PM1985/023/EG

SUBJECT: DP/IND/036 - CONTRACT NO 84/66
- EXPERTS FINAL REPORT

by

Erica Granberg

1 PROJECT AREA

Accepted as a part of the expert group after the work in India was completed.

2 HOME OFFICE

2.1 Training of Indian engineers

Responsible for planning and arranging the entire schedule for all the participants in the training program involved a major part of the work.

The following refractory engineers from SAIL

Mr. R.S. Dahiya
Mr. S.D. Majumdar
Mr. L. Tiwari
Mr. S.K. Garai

have participated in a training program of 4 weeks at MEFOS. A lecture was given in:

- Slag coating practice for a Combined Blown Converter.

A two day study trip to Österreichisch-Amerikanische Magnesit AG, Radenthein, was arranged. This included:

- A visit to the mine
- Screening, benification, grinding and sinter plant
- Brick producing plant
- The research center
- Quality control
- A concluding discussion in which special consideration was taken regarding Indian conditions.

MEFOS
METALLURGISKA
FORSKNiNGSSTATIONEN

Forskningsobjekt	Konto	Datum	Reg nr
	4449	1985-05-02	PM1985/024/PK

SUBJECT DP/IND/036 - CONTRACT NO 84/66
EXPERTS FINAL REPORT

by

Pekka Kuusela

1 PROJECT AREA

- Technical discussions in Ranchi, India 29/10-3/11 -84.
- Technical discussions in Ranchi and a visit to Bokaro Steel Plant 9/12-16/12 -84.

2 HOME OFFICE

2.1 Expert studies on combined blowing

A draft report, MF85019, was delivered to UNIDO in Vienna, UNDP in Delhi and SAIL in Ranchi in the end of March 1985. The aim of the report is:

- to compare combined blowing with LD steelmaking, advantages and disadvantages
- to made a short description of known combined blowing process
- a short description of pre-treatment of hot metal
- economical aspects with combined blowing and hot metal pretreatment

2.2 Pilot-plant tests

15 pilot-plant tests were carried out in the 6 ton universal converter at MEFOS with Indian raw material. This work involved:

- preparation work
- carrying through the trials
- evaluation work
- trial-report
- education of Indian engineers in pilot-plant operation

2.3 Training of Indian engineers

A number of lectures were given to Indian engineers such as:

- pilot-plant trials, equipment
- raw materials, addition program
- sampling, process-control
- preparation work
- leakages in CB-converter, prevention of leakages

The following metallurgists from SAIL were participating:

Mr R Sau
Mr A Kundu
Mr S Ghantasala
Mr A Bhandopaday
+ 6 steelworks engineers who were participating in the pilot-plant trials

2.4 Trial report

- All the results from the pilot-plant trials are shown in a trial report which will be presented in Vienna second week of May 1985.
- Trial report also includes discussions and conclusions from the pilot-plant trials.

MEFOS
METALLURGISKA
FORSKNINGSSTATIONEN

Forskningsuppdrag	Konto	Datum	Reg nr
	4449	1985-05-06	PM1985/025/BD

SUBJECT DP/IND/036 - CONTRACT NO 84/66
EXPERTS FINAL REPORT

by

Bodil Dahlberg

1 PROJECT AREA

- Technical discussions in Ranchi, India 29/10-3/11 -84.

2 HOME OFFICE

2.1 Expert studies on refractory technology

A draft report, MF85021, was delivered to UNIDO in Vienna, UNDP in Delhi and SAIL in Ranchi in the end of March 1985. The aim of the report is:

- to present refractory techniques in combined-blown converters in Japan and Europa
- to comment on the Indian conditions in the field of converter practices
- to give recommendations regarding lines of development to achieve improved practice in India

During Mr Lindfors third visit to India, February 05-09 1985, drawings for converter bottom brick work were sent to MEFOS for comments. The comments, mailed to Ranchi 1985-02-27, consisted of the following:

1 Stability of bottom brick work for curved bottom vis-a-vis flat bottom
2 Location of permeable elements
3 Technical comments regarding the draft specification on refractories
4 Qualities of refractories

2.2 Training of Indian engineers

The following refractory engineers from SAIL,

Mr R S Dahiya
Mr S D Majumdar
Mr L Tiwari
Mr S K Garai

have participated in a training programme of 4 weeks at MEFOS. A number of lectures were given such as:

- Testing of raw materials for basic bricks
- Test methods for basic bricks
- Repair and maintenance of refractories
- Lining techniques and brick laying pattern

MEFOS

METALLURGISKA
FORSKNINGSSTATIONEN

Forskningsuppgift:	Konto:	Datum:	Reg nr:
	4449	1985-05-08	PM1985/026/NOL

Distribution:

SUBJECT: DP/IND/036 - CONTRACT NO 84/66 - EXPERTS FINAL REPORT

by

Nils-Olov Lindfors

1 PROJECT AREA

- Technical discussions in Ranchi, India 1984-10-29--1984-11-03.
- Technical discussions in Ranchi and visit to Bokaro Steel Plant 1984-12-09--16.
- Technical discussions in Ranchi and Bokaro Steel Plant 1985-02-05--09.

2 HOME OFFICE

2.1 Expert studies on combined blowing

A draft report for the design of demonstration unit was presented in Ranchi and Bokaro 1985-02-05--09. This draft report was discussed throughly at the steelplant in Bokaro and a revised version was submitted end of March 1985.

Postadress
Box 812
S-951 28 Luleå

Gatuadress
Aronstorpsvägen 1

Telefon
0920 - 556 40

Telex
80482 MEFOS S

Postgiro
61800-9

Bankgiro
758-6555

2.2 Process control studies

Two reports in the field of process control were submitted in the end of March 1985:

- MF850124
  3.1 Process control studies
  - Design Development of static control
- MF85026
  3.2 Process control studies
  - Basic concept of dynamic PC based on MEFOS system

2.3 Training of Indian engineers

A number of lectures were given to Indian engineers during the training period, in the following fields:

- Process metallurgy of converter steelmaking
- Process control
- Design of combined blowing
- Designof LD-nozzles

MEFOS
METALLURGISKA
FORSKNINGSSTATIONEN

Forskningsuppgift:	Konto:	Datum:	Reg nr:
	4449	1985-05-08	PM1985/027/BB

SUBJECT: DP/IND/036 - CONTRACT NO 84/66
- EXPERT FINAL REPORT

by

Bertil Berg

1 UNIDO VIENNA

- Briefing one day September 1984
- Debriefing one day March 1985

2 HOME OFFICE

2.1 General responsibility for the contract to UNIDO

This work has included control of timeschedule, allocation of manpower resources for the project and internal acceptance of project reports before delivery to UNIDO and India.

2.2 Training of Indian engineers

A general information for the trainees about MEFOS. The information contained the follwoing:

- Background and purpose of MEFOS
- MEFOS organization and way of work
- Steelmaking in the Nordic countries

Before the end of the training period participation in summing up discussion was included.

MEFOS
METALLURGISKA
FORSKNINGSSTATIONEN

4449 1985-05-10 PM1985/029/MB

SUBJECT: DP/IND/036 - CONTRACT NO 84/66
- EXPERTS FINAL REPORT

by

Mikael Brunner

1 PROJECT AREA

- Technical discussions in Ranchi, India 1984-10-29--11-03
- Technical discussions in Ranchi and visit to Maharastra Electrosmelt Ltd. 1984-12-09--16

2 HOME OFFICE

2.1 Project management work

- Preparing progress report to UNDIO
- Planning of training of Indian engineers at MEFOS
- Planning of training of Indian engineers at Mo i Rana Steelworks, Norway
- Planning the pilot-plant test period

2.2 Expert studies (MF85025)

- Evaluation of MEL as pilot-plant for combined blowing studies
- Evaluation of MEL as stainless steel producing unit
- Evaluation of possible raw-material policies for India in connection to MEL-plant