MANGANESE SMELTING IN AUSTRALIA USING LUMP ORE AND SINTER

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ABSTRACT

Four (4) stages of development in manganese smelting have occurred in Australia.

(i) Smelting of manganese ore was established in Tasmania in 1962 with a 16,000 KVA furnace based on an abundance of hydro electric power and using imported South African ore to produce an alloy grade of 70% Mn.

(ii) In 1966 a major ore body was developed at Groote Eylandt, the GEMCO operation. Coupled with the installation of a second 16,000 KVA furnace this provided the basis for an independent alloy industry to meet future needs. With the high grade ore it was possible to produce standard HC FeMn and SiMn by the Duplex process for maximum recovery of manganese units and a sound furnace operating practice was achieved.

(iii) Australian steel production increased from 6 MTPA in 1966 to 7.8 MTPA in 1974 and a decision was made to expand alloy production. In 1976 a third 27,000 KVA furnace and a 600 T.P.D. sinter plant, with some export capacity in alloy and sinter, was installed. The inclusion of sinter enabled controlling the oxidation state of the ore burden, with immediate benefits in operating cost through increased electrical loading, decreased specific power consumption and decreased coke rates.

(iv) TEMCO has recently successfully smelted low manganese to iron ratio lump ore of low silica content and coupled with both acid and fluxed sintering of ore fines from the GEMCO treatment plant, this will optimise the development of the ore body.

(v) With the basis of proven smelting blends of ore and sinter TEMCO is entering a further stage of development with increased alloy production by uprating furnace capacity from 69,000 to 94,000 KVA; and to maintain competitiveness through:

- reduction in manpower
- replacement of layer casting with casting machines to increase saleable yield and provide cleaner product
- installation of computer control to optimise smelting conditions and increase efficiency
- installation of energy recovery on furnace off-gas.

The development of smelting is complimentary to our GEMCO operation establishing our (BHP) position as an ore - alloy producer to be able to sell the manganese unit in the form of alloy or ore to suit the market place.

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INTRODUCTION

Ferroalloys, TEMCO

The Tasmanian Electro Metallurgical Co. Pty. Ltd. (TEMCO), a wholly owned subsidiary of the Broken Hill Proprietary Co. Ltd., commenced production of ferromanganese in 1962 with the commissioning of No. 1 Furnace (F1), rated at 16000 KVA. No. 2 furnace (F2), rated at 16000 KVA was commissioned in 1966. Production was based on high iron manganese ore imported from South Africa and alloy grade was 70% manganese. With the advent of the Groote Eylandt manganese deposit it was possible to produce standard high carbon ferromanganese (76% Mn) and to produce silicomanganese by the Duplex process for maximum recovery of manganese units.

In 1976/77 an expansion of facilities took place and No. 3 furnace (F3), rated at 27000 KVA for manganese alloy production, No. 5 furnace (F5), a 45000 KVA ferrosilicon furnace and a manganese ore sinter plant were commissioned.

In 1984 a three year modernisation programme of the manganese alloy furnaces at a cost of $50 million commenced that will include uprating F1 and F2 to 29 MVA and F3 to 36 MVA, casting machines to replace layer casting, furnace computer control and an energy recovery unit. The ERU will burn furnace off gas and produce 10.5 MW of electrical energy.

Manganese Ore, GEMCO

The Groote Eylandt Mining Co. Pty. Ltd. (GEMCO) is a wholly owned subsidiary of BHP Australia. GEMCO was formed in 1964 with the initial objective of supplying 70,000 tonnes per year of dressed ore to meet BHP's (Australia) manganese requirements To market ore overseas, in 1968 preparation began for the design and construction of a beneficiation plant to produce 1 million tonne per year of lump ore.

The plant was designed to handle the wider range of ores to be mined and produce a range of different products of consistent grade and quality. The plant went into full production in 1972, and has a present capacity of 2 million tonne per year.

The manganese ore occurs as a tabular body within lower Cretaceous sands and deposition appears to have been in shallow tidal areas by precipitation of manganese oxides from sea water. The major ore types consist of recemented pisolites and massive structures with some horizontal zoning from cemented to loose pisolites and textureless ore. The principal ore minerals are pyrolusite, cryptomelane and psilomelane. The reserves of ore are at least 300 million tonne of high grade (average 40% manganese) with potential for additional tonnages to be proved.

The ore is mined by open cut methods from various quarries simultaneously and blended to produce the required products. The run of mine ore is crushed, scrubbed and sized, and if required by product specification, fed through lump ore or fine ore dense medium separation circuits. The product ore is then stockpiled for blending and shipment. The beneficiation circuit is provided in Figure 1.

RAW MATERIALS

Raw materials for the manufacture of ferromanganese and silicomanganese are sourced within Australia and typical analyses are provided in Table 1.

From 1962 to 1966 TEMCO imported high iron manganese ores for ferromanganese production which limited the grade to 70% manganese. When Groote Eylandt came on stream, standard high carbon (76%) ferro-manganese could be produced and metallurgical lump ore was smelted exclusively until 1976.

The Groote Eylandt deposit includes a high proportion of loose pisolitic ore and to increase the utilisation of the body, a sinter facility was constructed at TEMCO, Bell Bay in 1976. This also afforded the opportunity to include prereduced ore in the charge and considerable experience has been gained with various sinter/ore blends.

A significant vertical grading occurs within the ore body due to a replacement of manganese by iron in the ore types, and to allow for better exploitation of the mined ore, TEMCO has recently commenced smelting of high iron lump ore in ferromanganese.

Silicomanganese is produced from ferromanganese slag, silicomanganese grade sinter, and manganiferous ore for grade control.

Quartzite for silicomanganese is sourced from Beaconsfield in Tasmania; fluxes in the form of dolomite from Androssan, South Australia, and limestone from Beaconsfield are utilised for ferromanganese and silicomanganese.

Metallurgical coke is used as the reductant and is obtained from screenings at the Newcastle and Whyalla Steelworks.

Raw materials preparation consists of crushing manganese ore to -75mm and coke to -15mm. Screening to remove fines is essential for maximum smelting efficiency. Lump ore, quartzite and ferromanganese slag are screened at 10mm, and coke at 6mm. The removal of fines in raw materials has increased charge porosity, and reduced power consumption, top temperatures and fume loss. The fines are included in the constituents for sinter production, together with alloy fines. In this way complete utilisation of raw materials is practiced, and smelting conditions in the furnace are enhanced.

Sintering of manganese ore fines has produced a hard porous sinter, with better physical properties than iron ore sinters. Sinter hardness is not equal to manganese ore but withstands degredation when transported long distance and during multiple handling. About 5% fines of -6mm are generated during shipping.

The flexibility of the sinter strand affords TEMCO a useful outlet for ferromanganese slag fines, quartzite fines and sized raw material spillages. These materials when proportioned in the sinter mix provide economic additions for silicomanganese smelting.

SINTERING PROCESS

The sinter machine has a grate area of $36m^2$ and incorporates on-strand cooling (details in Figure 2). Although initially designed to produce 600 tonne per day, improved raw mix feeding control and recent increase in sinter suction has improved sintering rates with an average production of 800 tonne/day and peak production of 900 tonne/day. The granular pisolites are amenable to sintering and production rates of $1.4t./m^2/hour$ are achievable for standard 56% manganese grade.

Acid Sinter

Acid sinter productivity correlates well with the manganese grade and the amount of bonding phase - tephroite and glass; those ores with high gangue contents giving lowest productivity, (refer to Figure 3). The tumbler index of the sinter decrease as the amount of bonding phase increases; glass and silicates are brittle material, and as their concentration increases there is less matrix material of hausmanite and primary ore to bond together, and the strength of the sinter decreases.

A quantitive mineralogical analysis of acid sinter:

Phase	Volume
Hausmanite (Fe, Mn_3O_4)	60
Jacobsite (Mn_3O_4)	8
Tephroite (Mn SiO_4)	12
Glass	17
Primary Ore	3
Magnetite	-
Dicalcium Silicate	-
MnO	-

Basic Sinter

Sinter production to date has been almost exclusively acidic. Previous production of basic sinter made with 1.0 - 5.0mm sized limestone resulted in reduced sinter productivity and was unstable during storage due to free CaO reacting with moisture. A more recent campaign using agricultural grade limestone of less than 0.50mm yielded higher sintering rates than acid sinter, and with equivalent tumbler indices. Degredation occurred after storage of 2 months, but granulation was coarse. Smelting of the basic sinter in ferromanganese production resulted in reduced power consumption and coke rates.

More extensive trials with basic sinter will be undertaken in ferromanganese and silicomanganese.

TEMCO have placed emphasis on physical size and strength for material handling to meet customer requirement rather than reducibility and reduction degredation indices and the influence on heat/mass transfer in the furnace.

The recent smelting trial of basic sinter with the majority of sinter in the size range 6-25mm showed an improvement in productivity of 3% signifying the importance of high temperature properties.

Research will continue on correlating sinter basicity, reducibility, degradation indices, coke rate, and quantitive mineralogical phase analyses, to obtain the best sinter types.

Work has also commenced on the inclusion of sand tailings of metallurgical fines and high grade fines type analysis in the size range 0.5 - 1.00mm of MF and HGF sinter mixes. Sand fines to date have been stockpiled at Groote Eylandt. The addition of sand reduced air flow through composite sinter mixes, and increased the optimum feed mix moisture addition, but did not have a significant effect on acid sinter produtivity and quality. In manganese ore sintering the controlling factor appears not to be size distribution of feed but rather its chemical composition. It is envisaged that lowering the bottom size of sinter fines will not affect sintering characteristics provided the manganese content is monitored.

IMPROVEMENTS OBTAINED FROM THE USE OF SINTER IN MANGANESE ALLOY PRODUCTION AT TEMCO

1. Increased Metallurgical Efficiency

Sinter has improved porosity and allowed better distribution of reduction gas through the charge, with lower escape gas velocity that has resulted in a lower top temperature due to better heat transfer and considerably lower fume and dust losses in the furnace gas. When smelting 65% sinter, stack losses have been reduced by 250%.

2. Lower Specific Power Consumption

As the proportion of sinter is increased there is a reduction of power consumption of about 5% with 40% sinter in the charge. Power consumption then increases somewhat to 65% sinter.

The increase in thermal efficiency with sinter has compensated for the loss of heat in the furnace from the exothermic reactions involved in the reduction of MnO_2 to Mn_2O_3, and Mn_2O_3 to Mn_3O_4 with CO.

3. Stability of Furnace Operating Conditions

This has been one of the greatest advantages of manganese sinter, eliminating blows and eruptions in the furnace. The inclusion of sinter has increased porosity in the charge which allows a more uniform and free distribution of reduction gases through the charge. Furthermore, the sinter is pre-reduced so that if any tendency to bridging should occur the effect of increased subsidence is minimised and usually unnoticed. The reactions associated with manganese furnace eruptions are the dissociation of manganese dioxide and rapid smelting as the charge enters a super-heated smelting zone.

4. Complete Utilisation of Raw Materials

Using screened ore and coke fines from the plant, with additional unsaleable manganese ore fines from Groote Eylandt; the production of sinter has resulted in complete utilisation of raw materials.

5. Reduction in Electrode Paste Consumption

The reduction of specific consumption of electrodes has been as high as 45% in ferromanganese production. The reduction with silicomanganese smelting has not been so dramatic, but whereas slipping rates had been maximum or higher, the inclusion of 40% sinter in the ore blend has contained slipping to safe rates for the electrodes. The resulting sound electrode practices have prevented electrode breakages. The reduction in electrode paste is due primarily to lower oxidation state of the sinter, and to a lesser extent lower moisture content of the charge.

6. Lower Oxidation State

Manganese ore can be classified according to the degree of oxidation:

$$\frac{\Sigma\ (0)\ Mn + Fe}{Mn + Fe}$$

Metallurgical lump ore (MnO_2), of high oxidation state, dissociates exothermically at about 450°C high up in the furnace and the oxygen then reacts with CO gas, coke and electrode carbon, heating the upper charge.

Sinter (Mn_3O_4), of lower oxidation state, is thermally stable to about 1300°C and highly endothermic descending deep into the furnace.

Sinter/ore blends of intermediate oxidation state lower charge top temperatures and increase charge resistivity. This results in improved electrode penetration and thermal efficiency.

There appears to be an optimum oxidation state whereby all the CO gas reacts with all the dissociated oxygen from MnO_2. An excess of oxygen consumes additional carbon. TEMCO have achieved the best result with about 40% sinter in the blend.

	0% Sinter	40% Sinter	65% Sinter
Oxidation state	0.56	0.48	0.45
Fixed carbon/tonne, kg.	415	385	410
KWHR/tonne	2500	2375	2500

7. Increased Electrical Loading

Sinter has increased the resistivity of the charge by lower charge temperature and lower coke consumption, with consequent deeper electrode penetration so that the power loading of the furnace can be increased, maintaining normal electrical conditions of transformer MVA and power factor.

With 40% sinter in the charge the same electrode penetration can be retained when increasing the operating resistance from 0.95 to 1.05 mΩ and the furnace load can be increased by 4%.

8. Less Metallurgical Variation

With moderate proportions of sinter in the charge metallurgical fluctuations decrease through more constant and uniform smelting conditions, as evidenced by the necessity of less frequent charge changes.

9. Increased Quantity of Alloy Fines Recycled

Metal fines from crushing and screening are used to form ferroalloy casting beds. The metal fines readily become finely divided and only a small quantity can be returned to the furnace without adverse effects on furnace operations. The best method of treating these fines has been to include them in sinter feed. The manganese however, is oxidised in the sintering process but affords some reduction in coke breeze.

FERROMANGANESE SMELTING

A typical material balance of charge components for the production of FeMn is shown in Figure 4.

Trials have been conducted over the years with varying proportions of sinter and slag chemistry. Currently sinter constitutes 65% of the total ore input, as the best compromise between economic considerations and operations.

TEMCO have experimented with a range of slag basicities. At 0.45, slag volume is least but coke control is difficult and specific energy consumption is higher than expected.

Adopting a relatively high CaO + MgO/SiO_2 ratio of 0.60 for ferromanganese has improved furnace operating conditions and has controlled specific power consumption, and this has also made available a more suitable slag for producing silicomanganese.

TEMCO have recently introduced high iron metallurgical lump ore in the ore blend to release metallurgical lump into the export market.

SILICOMANGANESE SMELTING

Silicomanganese was originally produced to 11/13% specification in 1966, but to rationalise smelting specifications to meet the international market silicon grade was increased to 15/17% and later 16/18%. Silicomanganese is produced exclusively in No. 3 furnace, while Nos. 1 and 2 furnaces produce ferromanganese.

Past practice at TEMCO was to include manganese ore screenings in silicomanganese, where with the reduced gas make, sizing was not so critical. Sintering the ore fines with either MGF or SF and including in silicomanganese smelting has contributed to significant improvement in silicomanganese operations due to the high temperature stability and high melting point of sinter compared to ore.

The use of low melting point manganese ore results in slag formation occurring before the start of the reduction reaction

$$MnO + (1 + X)C = Mn_X + CO$$

at 1320°C. This leads to a reduction in the activity of manganese oxide and silica in the melt.
The use of sinter has also reduced the tendency of the furnace to clinkering.

A typical material balance for the production of silicomanganese is shown in Figure 5.

This includes a significant proportion of remelt materials from spillages, often finely sized, that could not be consistently returned to the furnace until using sinter as the other ore source of manganese with ferromanganese slag.

TEMCO's initial practice was to produce silicomanganese at a low slag basicity of around 0.45. In this region of the phase diagram the slag composition is on a steep slope of the liquidus surface and small variations in slag chemistry resulting in high melting point slags, difficult tapping conditions and what appeared to be freezing up of the sides of the furnace. The practice is now to use a basicity of 0.65 retaining the same molecular basicity of 0.90 to 0.93.

The high slag temperature of this region has promoted silicon reduction and less tapping difficulties occur in this more stable region of the liquidus surface.

FUTURE DEVELOPMENT

To achieve a more adaptable market strategy and cater for the ever increasing competitive market, TEMCO is entering a phase of modernisation that will increase manganese alloy production by 40% and reduce the operating cost by up to 35%. This will provide a springboard for increased market penetration.

This development is based on proven smelting methods with Groote Eylandt ore types that currently are not readily marketable - higher iron lump ores and lower grade fines. These ore types occur as side products from producing metallurgical lump ore and at a time when demand for metallurgical lump exceeds production capacity.

The programme is considered complimentary to the development of the Groote Eylandt ore deposit and the best utilisation of the concentrator to meet a buoyant export market.

The combined approach will establish BHP position as an economic ore-alloy producer to be able to sell manganese units in the form of alloy or ore to suit the dynamic demand of the industry.

Upgrading is intended to increase competitiveness through:

- reduction in manpower

- replacement of layer casting with casting machines and new size reduction methods to increase saleable yield, with better alloy presentation
- installation of computer control to optimise smelting conditions and increase efficiency
- installation of energy recovery on furnace off-gas
- installation of new wharf crane facility that will service larger bulk vessels, and at increased throughput capacity.

The $50 million modernisation will be completed in 1987 and includes the following technological advancement:

(i). Uprating F1 and F2 from 16,000 to 29,000KVA, and lowering gas emissions in line with environmental statutory regulations. This will be achieved by the installation of Elkem modular electrodes with improved gas seals and efficient 2 stage venturi gas scrubbers to replace Buffalo scrubbers. The modular electrode system utilises an equalising ring combined with the contact units that gives the best possible current distribution to the electrode casing, and higher paste baking rates for sound electrode management.

New raw material preparation plant will be installed with computerised proportioning and zone feeding. Automated charging using steep-angled conveyors will replace a telpher crane feeder.

(ii) Uprating F3 from 27,000 to 36,000KVA and computerised batching. The thickener in F3 water treatment plant has sufficient capacity to treat the proposed venturi units. The combined water treatment plant will have facilities for tar removal that will enable operating the furnaces with coal in the reductants, and includes ammonia stripping and cyanide destruction.

(iii) Computer control for improving process performance. TEMCO will adopt the Elkem Metals SAFEPAC modular system that includes the following main functions: furnace operating reporting, operator communication, electrode and transformer regulation, electrode slipping control, raw material proportioning control and maximum power demand control.

(iv) Introduction of casting machines for F1, F2 and F3. Extensive research into cooling control of manganese alloys at BHP Melbourne Research Laboratories and technical interchange with Japanese ferroalloy producers has led to their implementation. The study supports rapid cooling to initiate preferential surface cracking followed by adiabatic cooling to temper the alloy.

Casting machine discharge height has been designed to include breakage bars to minimis the need for further size reduction. Discharged alloy will be air cooled in concrete bunkers before being removed by front end loaders to a common product crushing and screening plant.

The casting machines of length 65 metres and 45 metres respectively will be supplied through Mizushima Ferroalloy Company, Japan.

Casting will be by direct feed and undertaken within one revolution of the machine for each tapping.

This technology with tapping fume collection will also combat air borne dust and fume nuisance within the plant.

(v) New product crushing and screening plant will be constructed that includes MMD sizing as test work has indicated MMD size reduction produces the least fines compared to jaw and cone crushing. The crushing units have been designed to cater for layer casting that will continue for selected markets.
The casting machine discharge is expected to require sizing only and provision has been made to by-pass the primary crusher.

(vi) Wharf crane throughput capacity will be increased by 100%.

This will be achieved by replacement of the existing crane by a rail mounted luffing and slewing crane capable of servicing vessels up to 45,000 DWT.

A significant feature of the French Caillard-Levage crane will be computer control that enables an optimum combination of hoisting, luffing and slewing to maximise the handling capacity.

(vii) An automated energy recovery unit will recover chemical energy of the off-gas from furnaces 1, 2 and 3. This will give an output of nominal 10.0 MW and is approximately 17% of the electrical energy requirement of the furnaces.

The off-gases will be cleaned to less than 30mg/Nm^3 in venturi scrubbers and cooled to 45°C to lower the saturated water vapour content of the gases, and then combusted in a Babcock radiant natural circulation water tube boiler.

The boiler consists of a fully water-cooled membrane tube wall construction and superheater comprising one secondary and two primary banks.

The maximum performance of the boiler will be 51 tonne/hour of steam production at a pressure of 6750 KPa and a temperature of 485°C. From the boiler the furnace gas at 630°C, will proceed through a economiser, and then a combustion air heater with a final exhaust temperature of 160°C.

The combined gas/oil burner has a gas burning capacity of 17,800 Am^3/hour (saturated 45°C); and fuel oil burner capacity of 720 kg/hour or capable of 50% of the boiler rating. Supplementary oil firing will be used intermittently to generate additional power for controlling maximum demand of the total plant power. Steam produced in the boiler unit will power a Siemens turbine 11 KV alternator to 12.5 MW at a 0.8 power factor.

The steam boiler will be fully automated and remote controlled from furnaces F1 and F2 control room by one operator.

The ERU parameters are shown in Table 3.

CONCLUSION

TEMCO is embarking on a modernisation programme in a climate of decreasing manganese alloy consumption. The development of the divided refining process in steelmaking whereby manganese in the form of raw ore is added at various stages of the steelmaking process to reduce the need of manganese alloys, coupled with the trend to utilise an ever increasing proportion of continuously cast steel which increases the yields without increasing the steel make, resulted in the decrease in demand for manganese alloys.

This may be considered a bold undertaking in a market where supply is exceeding demand, and many companies have idle capacity.

TEMCO consider it has the necessary justification for this undertaking through:

1. Selective use of lump ore and ore fines fractions at competitive prices on manganese unit bases that also maximises the production of lump ore for the export market.

2. Flexibility of sinter addition that optimises the oxidation state, and results in operations that are comparable to other ferroalloy producers who have available a wider selection of manganese ores for blending.

3. Availability of low priced hydro electric power.

4. Strategic location, adjacent to an all weather port and with freight advantages into South East Asia, Persian Gulf and West Coast of America regions, compared to other producers.

5. Political stability.

The upgrading programme will improve TEMCO's flexibility and performance, increase competitiveness and market penetration through the interplay of product volume and cost.

Cost economies will be achieved by:

1. Fixed costs spread over a larger production volume.

2. Computer control to optimise smelting conditions and increase efficiency and uniformity of product.

3. Replacement of existing layer casting with cast to size product that will meet stringent market sizes at increased yields and with better physical presentation.

4. Reduced labour cost through replacing labour intensive raw material handling, product handling plant, and wharf crane facility to handle larger bulk raw material deliveries at faster throughputs.

5. Installation of energy recovery to reduce overall plant energy cost.

6. Flexible and versatile plant for producing moderate tonnage ferromanganese/silicomanganese within an existing infrastructure that could not be achieved on a green field site.

7. Installation of technically advanced modular electrode assembly (of low reactance, improved baking characteristics, lower paste consumption) to replace inefficient units.

8. Improved work environment to augment an industrially stable climate.

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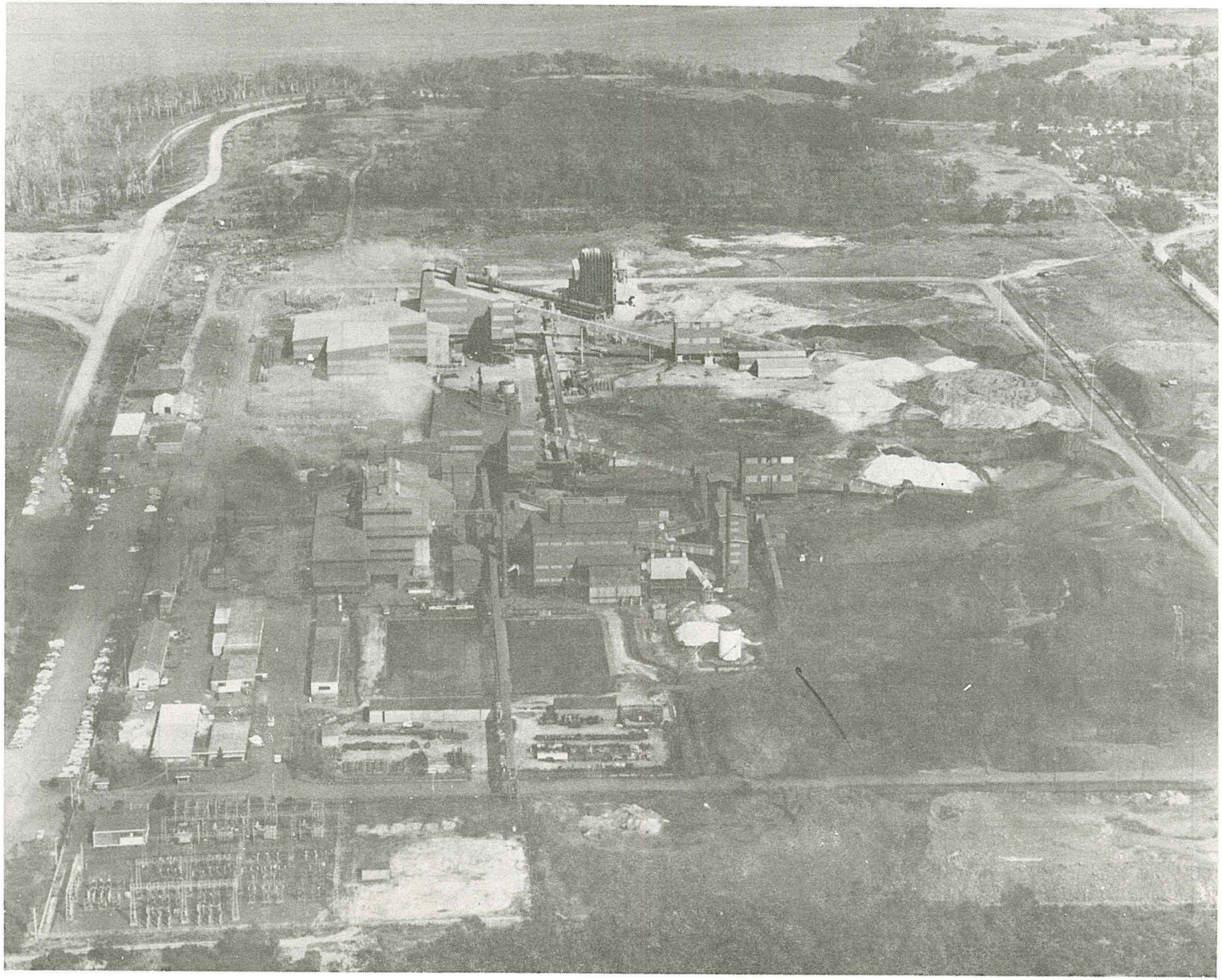
Acknowledgement:

The authors wish to thank Les Jensen and Vicki Porter for their assistance.



A VIEW OF THE TASMANIAN ELECTRO METALLURGICAL CO. AT BELL BAY, TASMANIA.

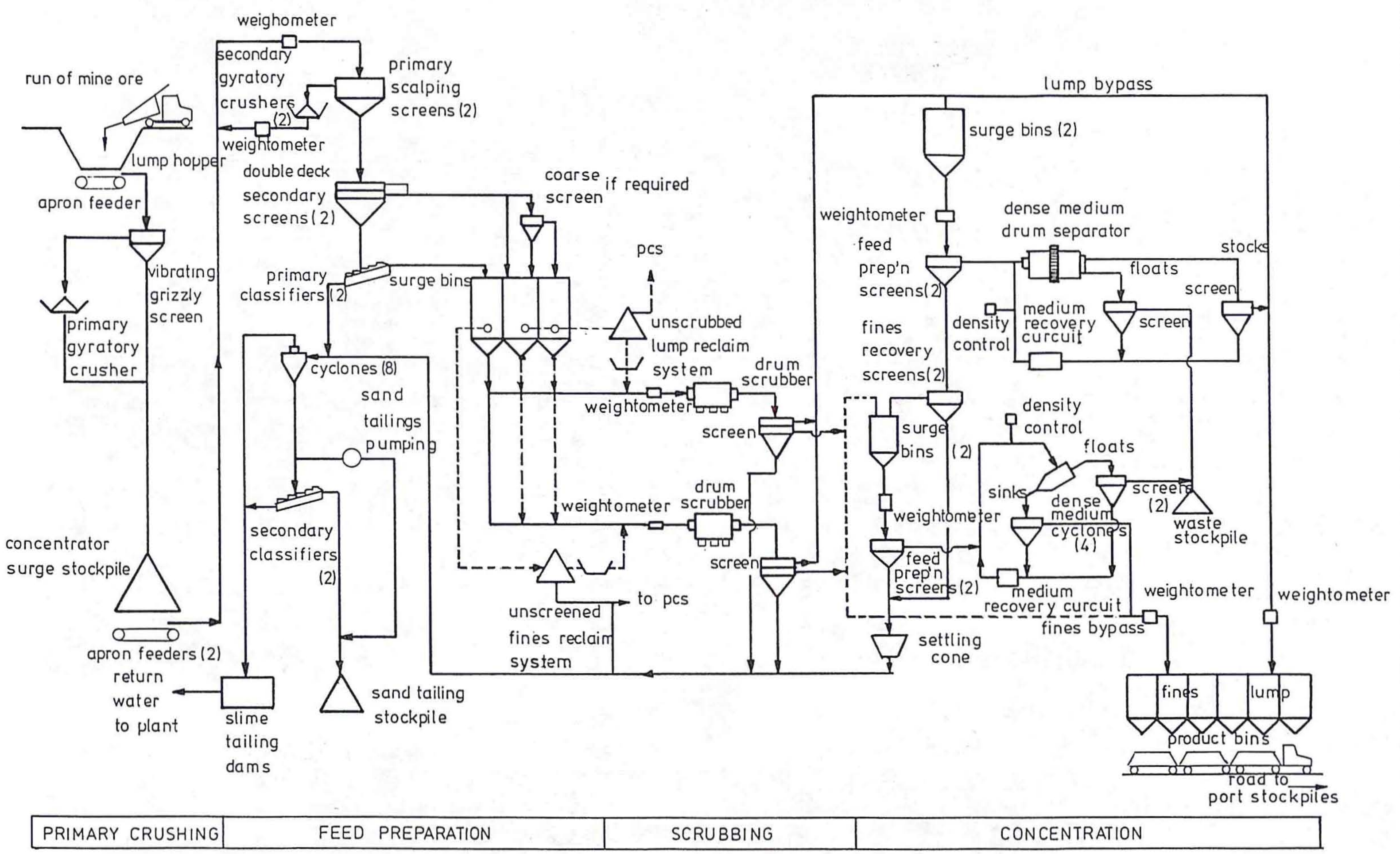


Fig . 1

GROOTE EYLANDT CONCENTRATOR PLANT FLOWSHEET

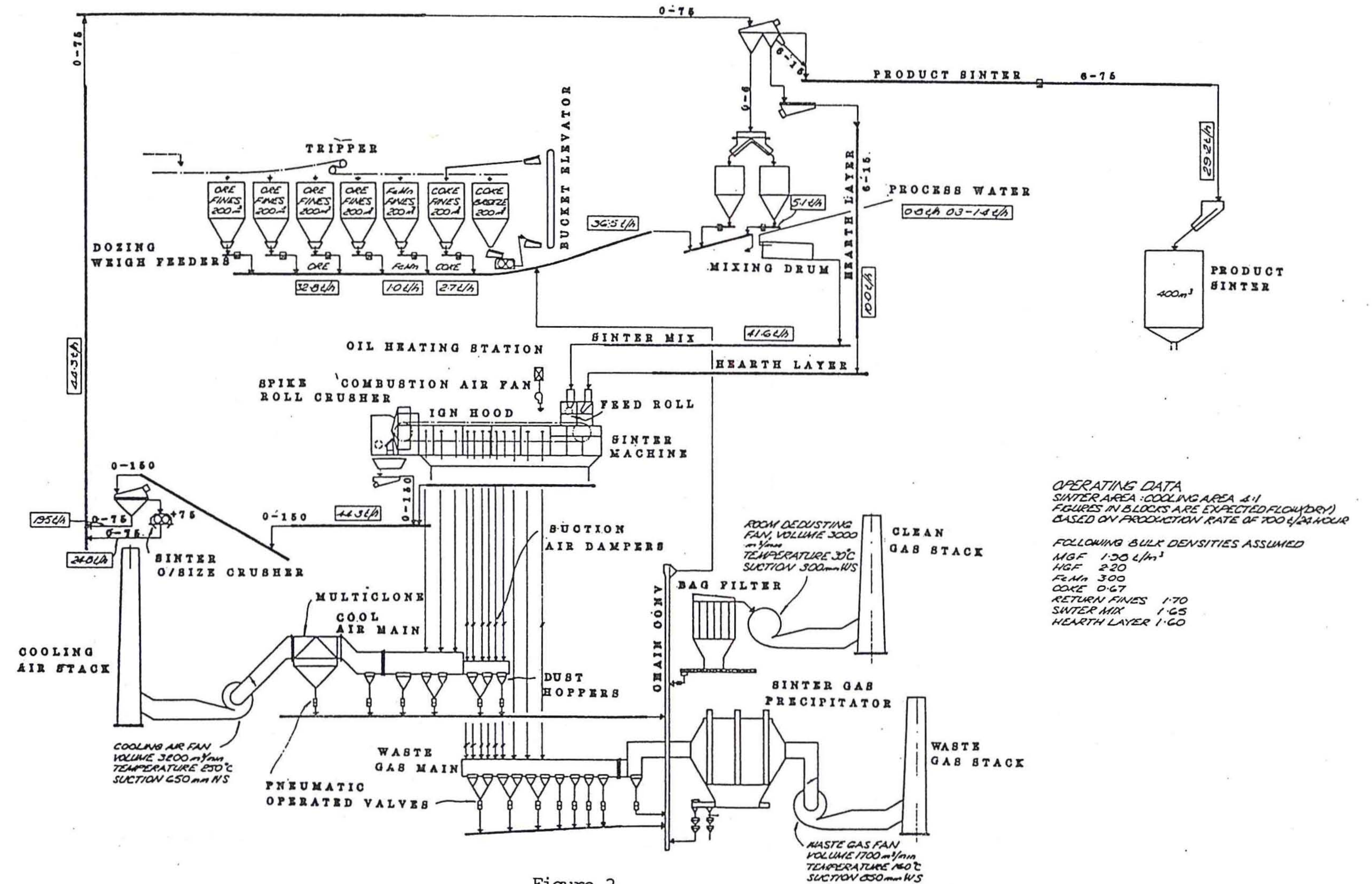
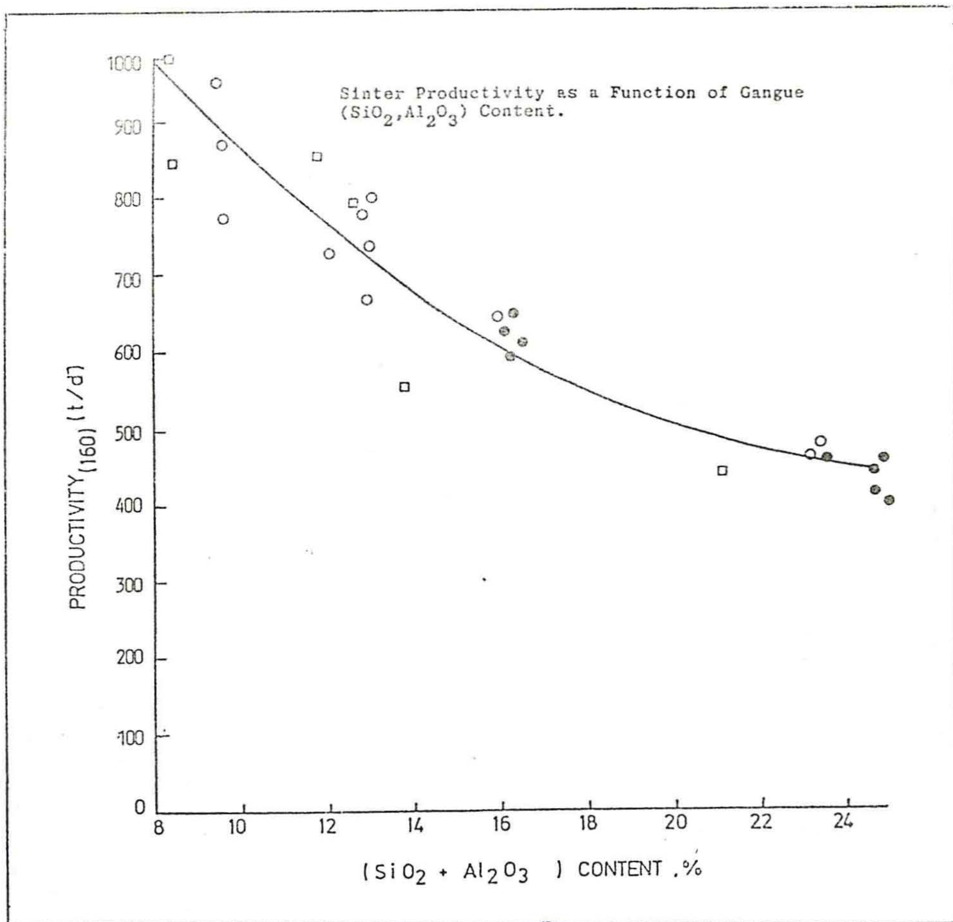


Figure 2.

SINTER PLANT FLOW DIAGRAM


Sinter Productivity as a Function of Gangue (SiO_2,Al_2O_3) Content.
PRODUCTIVITY(160) (t/d)
0
100
200
300
400
500
600
700
800
900
1000
8
10
12
14
16
18
20
22
24
(SiO_2 + Al_2O_3) CONTENT ,%

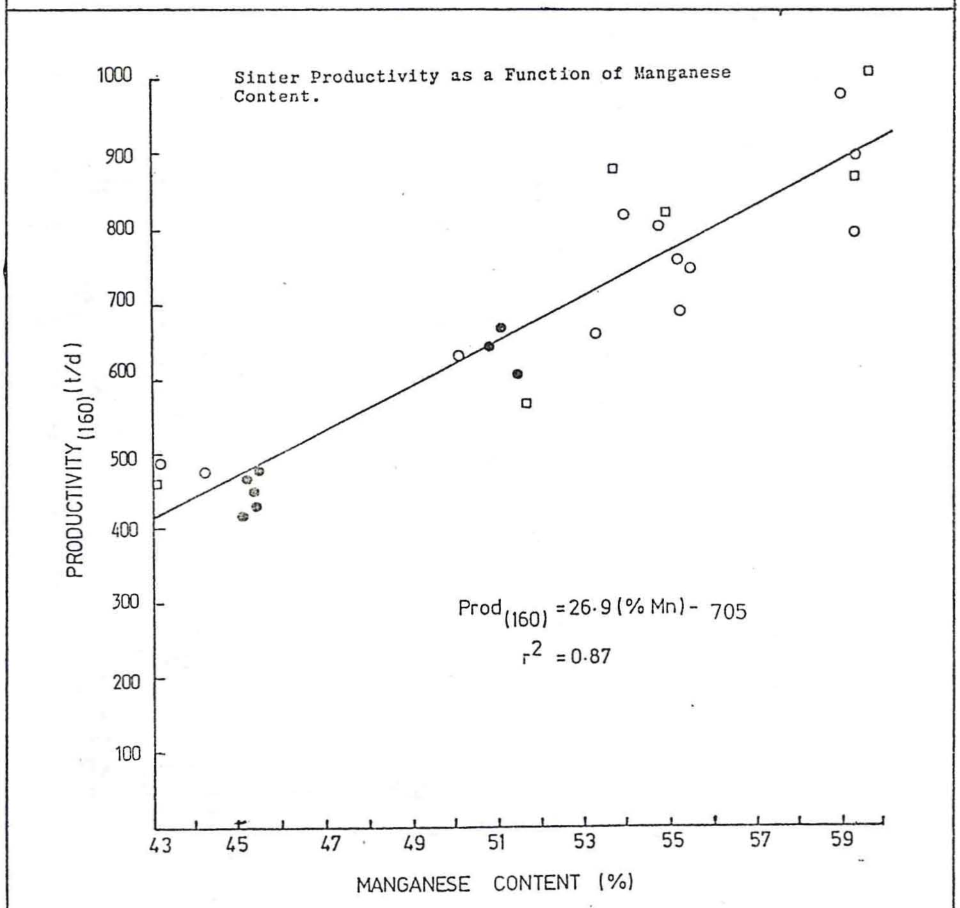

Sinter Productivity as a Function of Manganese Content.
PRODUCTIVITY(160) (t/d)
100
200
300
400
500
600
700
800
900
1000
43
45
47
49
51
53
55
57
59
MANGANESE CONTENT (%)
$Prod_{(160)} = 26.9 (\% Mn) - 705$
$r^2 = 0.87$

Figure 3.

MATERIAL BALANCE

PRODUCT: 76% FeMn - High Fe Lump Ore

MATERIAL	T/T	Mn	MnO	Fe	SiO_2	CaO	MgO	Al_2O_3	C
Iron Ore	0.058	0.001		0.037	0.002				
F.G. Limestone	0.140				0.005	0.068	0.005	0.001	
N.C. Coke	0.412	0.001		0.005	0.032	0.002	0.004	0.016	0.350
M.F. Sinter	1.149	0.654		0.060	0.067	0.001		0.056	
High FeMn Ore	0.709	0.305		0.058	0.033			0.038	
TOTALS	2.467	0.961		0.160	0.139	0.071	0.009	0.111	0.350
Metal	1.000	0.765		0.160	(0.0030)				0.068
Slag	0.584	0.158	0.204		0.132	0.071	0.009	0.111	
Remainder		0.039							
Average Analysis Slag (%)		27.0							
Calc. Analysis Slag (%)			34.9		22.6	12.1	1.5	18.9	

Short $\frac{\text{Base}}{\text{Acid}}$ = 0.60   Molec $\frac{\text{Base}}{\text{Acid}}$ = 1.97

Manganese Recovery Metal = 79.6%
Manganese Recovery Slag = 16.4%
Manganese Loss = 4.0%

kg/kg Ores = 1.91
Coke Rate = 0.41
F.C. Ratio = 100.0

Power : 2500 kWhr/t

Paste : 11 kg/t

MATERIAL BALANCE

PRODUCT: SiMn

MATERIAL	T/T	Mn	MnO	Fe	SiO_2	CaO	Mg	Al_2O_3	C
M.F. Sinter	0.669	0.381		0.035	0.039	0.001		0.033	
Iron Ore	0.119	0.001		0.077	0.004			0.001	
F.G. Limestone	0.298			0.001	0.010	0.144	0.011	0.002	
Dolomite	0.149			0.001	0.001	0.055	0.025		
FeMn Slag	1.000	0.270			0.226	0.122	0.015	0.189	
Quartzite	0.492				0.478		0.001	0.003	
Remelt	0.300	0.133		0.027	0.096			0.006	0.005
Coke	0.406			0.004	0.032	0.001		0.015	0.345
FeSi	0.048			0.010				0.003	
TOTALS	3.482	0.785		0.155	0.886	0.323	0.052	0.252	0.350
Metal	1.000	0.665		0.155	(.1450)				0.020
Slag	1.439	0.101	0.130		0.575	0.323	0.052	0.252	
Remainder		0.020							
Average Analysis Slag (%)		7.0							
Calc. Analysis Slag (%)			9.0		40.0	22.4	3.6	17.5	

Short $\frac{\text{Base}}{\text{Acid}}$ = 0.65   Molec $\frac{\text{Base}}{\text{Acid}}$ = 0.93

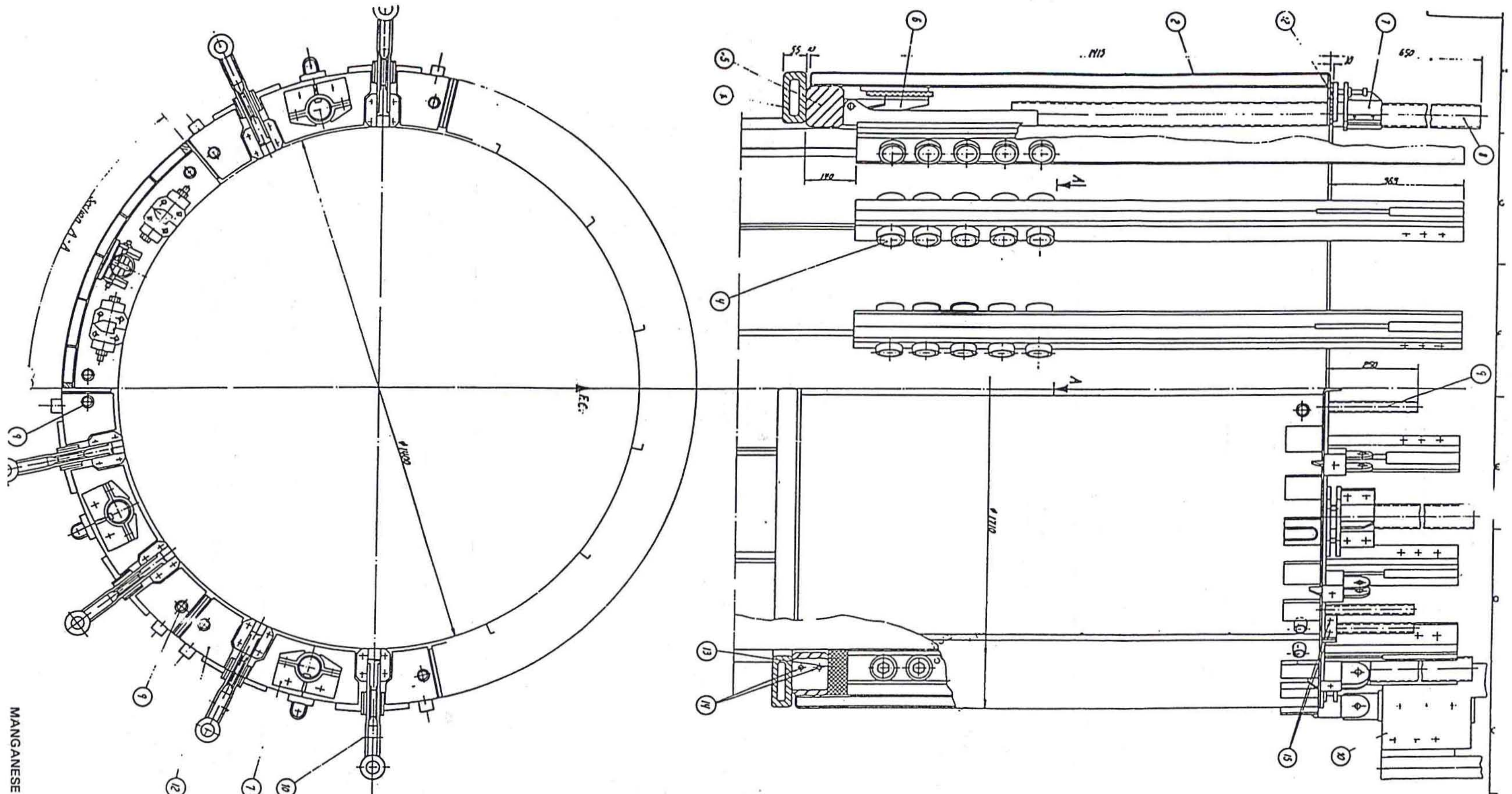
Manganese Recovery Metal = 84.7%
Manganese Recovery slag = 12.8%
Manganese Loss = 2.5%

kg/kg Ores = 0.788
Coke Rate = 0.406
F.C. Ratio = 100.0

Power : 3950 kWhr/t

Paste : 33 kg/t

Figure 4.



MODULAR ELECTRODE

Figure 5

TABLE 1

RAW MATERIAL ANALYSIS

MATERIAL	SOURCE	V.	FC.	ASH	Mn	Fe	SiO_2	Al_2O_3	CaO	MgO	P
Manganese Ore Metallurgical Lump	Groote Eylandt				50.0	3.3	5.6	4.3	0.2	0.1	0.07
Manganese Ore High Iron Metallurgical Lump					43.0	8.2	4.6	5.3	0.2	0.1	0.10
Manganese Ore Metallurgical Fines					49.2	4.2	4.6	4.5	0.2	0.1	0.08
Manganese Ore Premium Fines					52.3	2.8	4.0	3.2	0.2	0.1	0.07
Manganese Ore Siliceous Fines					39.5	8.1	11.5	6.8	0.2	0.1	0.07
Manganese Ore High Grade Fines					46.5	5.0	6.5	5.2	0.2	0.1	0.06
Ferromanganese Acid Sinter	Temco				56.0	5.4	6.5	4.9	0.2	0.1	0.10
Ferromanganese Basic Sinter	Temco				51.8	5.2	6.2	4.8	0.1	0.4	0.10
Coke	Newcastle, NSW	0.7	85.0	14.5		0.8	7.8	3.9	0.3	0.1	0.06
Coal	Newcastle, NSW	34.0	56.0	8.0		0.2	5.2	2.5			0.03
Coke	Whyalla, S.A.	1.2	80.0	19.0		1.0	10.5	4.8	0.9	0.2	0.04
Quartzite	Beaconsfield, Tas.					0.3	98.0	0.7	0.01	0.03	0.01
Limestone	Beaconsfield, Tas.					0.2	3.4	0.8	48.4	3.4	0.04
Dolomite	Ardrossan, S.A.					0.5	1.5	0.3	30.0	20.5	0.01
Iron Ore	Whyalla, S.A.				1.1	64.7	3.8	0.7	0.4	0.2	0.04

TABLE 2

	No. 1 Furnace	No. 2 Furance	No. 3 Furnace
First commissioning year	1962	1966	1977
Product	FeMn & SiMn	FeMn & SiMn	FeMn & SiMn
Type	Rotating - closed	Rotating - closed	Stationary - closed
Shell diameter (mm)	10,000	10,000	11,000
Shell depth (mm)	5,640	5,640	5,425
Hearth diameter (mm)	9,235	9,235	10,200
Top of shell to hearth (mm)	3,705	3,705	4,130
Electrode diameter (mm)	1,420	1,420	1,550
Electrode spacing (f/f mm)	1,980	1,980	2,150
Transformer capacity (kVA)	27,000	16,000	27,000
Primary voltage (V)	22,000	22,000	22,000
Secondary voltage	92 - 154V 53 - 89V	110 - 182V 64 - 106V	150 - 235V 87 - 136V
Furnace Reactance	0.95	0.95	0.95
Cos Ø	0.69	0.69	0.61
Tap changer	On load 21	On load 19	On load 21
Tapholes	3	3	2
Hearth thickness			
- Brick (mm)	372	372	295
- Carbon block	-	-	1,000
- Carbon Paste	1,543	1,543	-
Operating Data:			
Furnace load (MW)	20 (FeMn)	20 (FeMn)	20 (SiMn)
Electrode current (KA)	86	86	86
Current Density (A/cm²)	5.4	5.4	5.1
Westley C_3	11.7	11.7	12.9

TABLE 3

ENERGY RECOVERY PARAMETERS

	Ferromanganese	Silicomanganese
Furnaces:		
Furnace load (MW)	36	22
Gas production (Nm/hr)	9400	3500
Dry dust content (Kg/hr)	1100	350
Outlet dust (Kg/hr)	0.28	0.105
Venturi efficiency (%)	99.9	99.9

Gas Temperatures:	
Burner outlet (°C)	1300
Leaving superheater	880
Leaving economiser	710
Leaving air heater	160
Rating:	
Boiler thermal duty (MW)	30.8
Nett heat released by combustion of furnace gas	32.9
Nett heat released by combustion of fuel oil	8.0
Steam Turbine:	
Pressure (KPa)	6500
Temperature (°C)	485
Flow (t/hour)	41
Gross energy output (MW) of 11KV	10.2 (12.5)*
Power factor	0.8
Transformer 11KV/22KV	0.07 (0.08)
Nett power at 22KV	10.1 (12.4)
Nett power less total auxiliary power consumption	9.7 (11.9)

* With supplementary fuel oil.