H.C. FERRO MANGANESE PRODUCTION IN AN OPEN FURNACE OPERATING WITH THE "TWO TAP" PROCESS

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A B S T R A C T

The paper reports the experience of CARLO TASSARA Stabilimenti Elettrosiderurgici running an open furnace producing H.C. Ferro Manganese.

At the end of the sixties Tassara needed to start once more the production of H.C. Ferro Manganese.

Being the italian geoeconomic situation very unfavorable, (no manganese ore, no coal, expensive power) investment and consumptions had to be low.

Tassara's choice was to install an open furnace, (suitable to be closed if necessary) and to run it under the "two tap" process.

The furnace (22 MVA) proved to be able to give good results.

The autors are giving information about the plant features, the handling of raw materials, the processes and the results.

INTRODUCTION

At the beginning of the sixties the production of ferromanganese in Italy was shared among various producers; each of them had a wide production program including a number of other alloys. With three exceptions all plants were located inside the country, far from the sea and close to hydroelectric power stations. Ferromanganese was produced in small electric furnaces, not even specifically designed for its production, using the low manganese basic slag process (about 13% Mn). Production cost were very high due to power consumption (up to about 2800 Kwh/ton), coke consumption, land transport, and low furnace capacities. As a consequence domestic standard ferromanganese became unable to compete against the imported product, mainly from France, Norway and Russia, domestic production decreased very steeply down to about 10% of the national demand. Market difficulties brought about a reorganization of the italian ferroalloys production, one of the first changements was the specialization of each producer in the production of a limited range of alloys; each producer made his own choice, manganese alloys were ours.

Some ten years later, in 1968, we were the only italian producer with an almost full range of manganese alloys, from spiegel iron to low carbon ferromanganese. I say "almost full range" because our production did not yet include H.C. ferromanganese which could not be produced economically with the facilities available at that time in our shop. We could not however accept any longer this void in our production first of all for commercial reasons and secondly because we needed high purity slags for the production of special grades of silico manganese and low carbon ferromanganese. We therefore decided to build a new plant to fill this gap. Some few starting points were set firm:

1. The new plant should be located near the sea in order to reduce ore transport costs. It should also be as close as possible to the consumers.
2. The chosen process should be really up to date to face competition succesfully.
3. The plant should be able to produce 50.000 ton/y for the italian market only.
4. The furnace size was therefore defined as a function of its capacity and specific power consumption. The furnace should be very flexiblein order to be adaptable to different processes as well as to the production of other alloys.

5. The plant should be as simple as possible in order to reduce investments, amortization and maintenance costs.

Keeping in mind these points we considered the existing plants and processes. At this stage we were particulatly impressed by a paper issued by Dr. Nasu where the author described the two tap process and the Mizushima furnace in which such process was carried out. Our technical staff, supervised by Mr. A.D. Manara, started to analyse advantages and disadvantages of such a plant and process. Two new main concept were adopted in this closed furnace, namely:

- The slag pool, which acts as a resistance and decreases and equalizes the temperature by distributing the heat.
- The shafts which recover the heat and make a first gas cleaning.

Each one of these two elements has its own effect: our problem, at that point, was to understand such effects, to interpretate the behaviour of the charge under these conditions and to evaluate the consequences deriving from the impossibility of stocking the charge due to the furnace cover.

Our experience and the results obtained by Lubatti with his furnace made us to realize that the slag pool was responsible of most of the advantages presented by the Nasu furnace and that such advantages could be still increased provided that a way could be found to control the charge and distribute it smoothly all over the furnace surface. In other words we became convinced that a good open furnace together with a good, well sized and well distributed charge could give the same economic results as a closed furnace equipped with shafts.

We carried out some experiments on a 4 MW furnace using a self fluxing charge: the results were very interesting - low power consumption, high manganese yield and very smooth furnace operating conditions - but not fully reliable because of the small dimensions of the furnace. We therefore decided to adopt the two tap process and to build an open furnace wich might be closed later on if the results were not as good as expected.

As far as the location of the new plant was concerned, we decided to build it in Cairo Montenotte; three were, and still are, the main advantages of this choice :

- Cairo Montenotte is in the baricenter of steel production in the industrial triangle of northern Italy.
- It is connected with the port of Savona by a ropeway served by a powerful unloading system. Thus from the economic point of view Cairo Montenotte is situated on the sea and in the country at the same time.
- In Cairo Montenotte it exists an important coke plant.

The size on the furnace was calculated on the basis of the following data :

Production	50.000 ton/y
Power consumption	2400 Kwh/ton
Furnace Power factor	0.7
Working time	8.000 hours/year

$$\frac{50.000 \text{ t} \times 2400 \text{ Kwh/t}}{8000 \text{ h} \times 0.7} = 21.5 \text{ MVA}$$

DESCRIPTION OF THE PLANT

The available land was not flat. At first sight it seemed that this fact would imply a considerable expense for the preparation of the land. This was not however the case since we managed to recover this additional cost by placing the shop at different levels so that the material can drop down and shorter belt conveyors are required. We saved something on foundation costs too.

The plant was designed foreseing a possible future expansion. Step by step we got to the present lay out which consists of :

- raw materials covered store (15 days capacity)
- dayly store and mixing plant
- furnace building
- casting hall
- maintenance shop
- Fe Mn crushing plant
- Products store and screening plant
- gas cleaning plant
- water cooling system
- social services
- offices

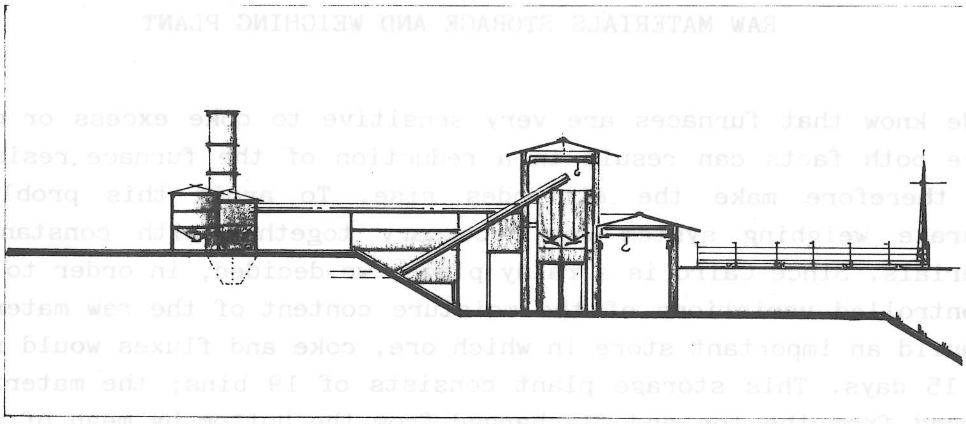

Fig. 1 cross section of the plant

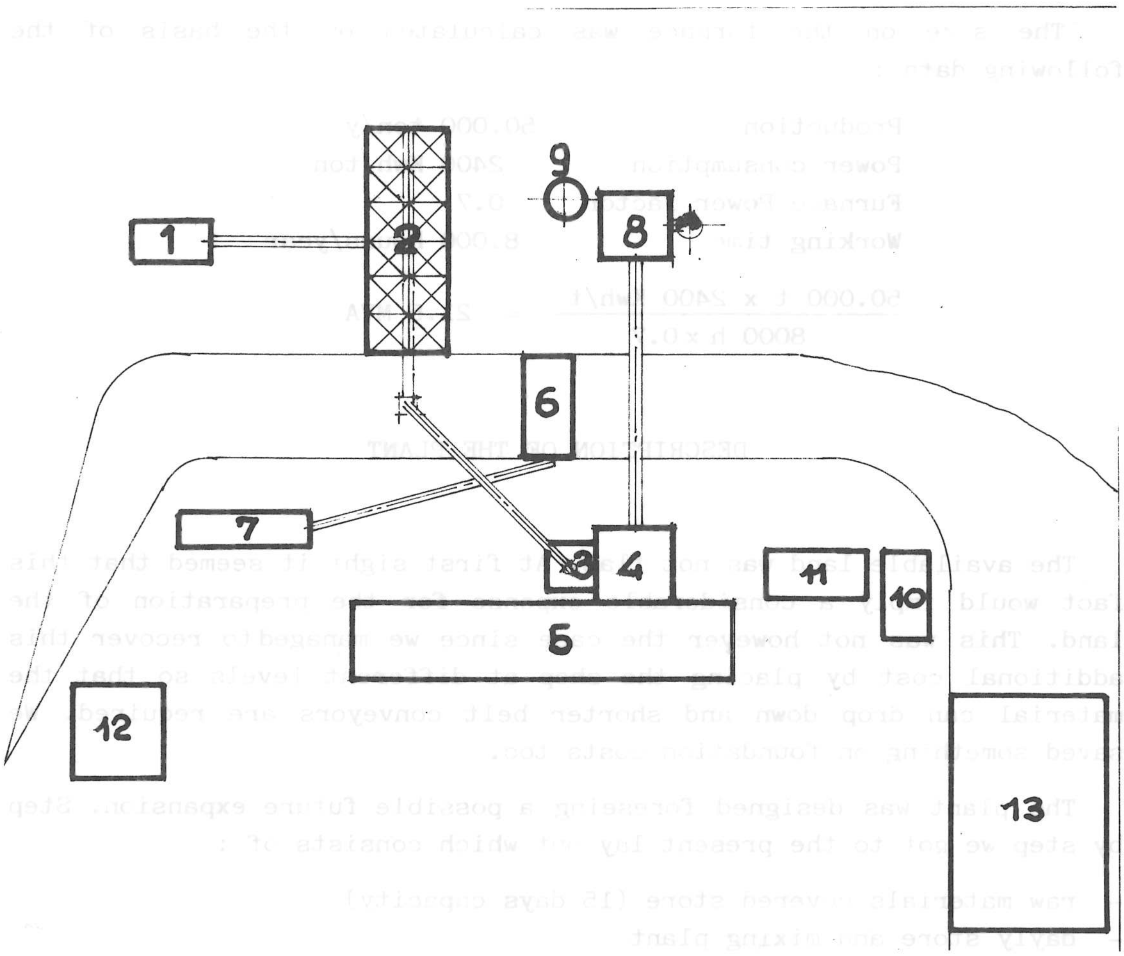

Fig. 2 Layout of the plant

1) ore crusher
2) raw material storage
3) mixing plant
4) Furnace building
5) casting hall
6) Fe Mn crushing
7) Fe Mn screening & storage
8) gas cleaning plant
9) dust pelletizer
10) water cooler
11) maintenance shop
12) services
13) electric power substation

RAW MATERIALS STORAGE AND WEIGHING PLANT

We know that furnaces are very sensitive to coke excess or defect since both facts can result in a reduction of the furnace resistance and therefore make the elctrodes rise. To avoid this problem an accurate weighing system was necessary together with constant raw materials. Since Cairo is a rainy place, we decided, in order to avoid uncontrolled variations of the moisture content of the raw materials, to build an important store in which ore, coke and fluxes would remain for 15 days. This storage plant consists of 19 bins; the material is charged from the top and discharged from the bottom by mean of a tele controlled belt conveyors system. Prior to charging, the ore is screened and the large pieces are crushed. The conveyor system takes the raw materials to the dayly store and weighing plant. The dayly store consists of 10 bins: 4 are used for the Mn ore, 2 for the coke, 1 for the Fe ore, 2 for the fluxes and the last one is left empty for special needs. Eight weighing instruments are contemporarily used. The weight of a single charge corresponds to one ton of product and the time required for one weighing operation is of the order of 60 seconds. The capacity of the plant is therefore sufficient for two furnaces.

We chose not to have a store of already mixed materials in order to :

- avoid segregation
- be able to change the mix in any moment without loosing time

This raw materials handling system has proved to be excellent for the following reasons :

- it is fully mechanized and controlled from the control room so that one man, eight hours per day, can alone supervise all the operations
- it produces a good charge, with an accurately controlled weight, moisture content and size
- it gives an accurately mixed burden
- it allows to operates mix changes in real time.

FURNACE BUILDING

Due to the concentration of chemical plants in the Cairo area both air and water are heavily polluted and very aggressive; steel buildings need anticorrosion protection and continuos cares, water cannot be used in the cooling systems due to corrosive agents in it. We therefore decided to use reinforced concrete for alla the buildings: only two inside floors in the furnace building were made of steel.

The furnace building is a peculiar one: on top of it there is a 32 tons crane, the one with which we erected quickly and easily the furnace. We still use it for maintenance works and it could be used to feed the furnace from the top should we decide to change to a top charging system. The building has besides a storage capacity of 130 tons of charge. It is therefore very high - three stores - and very heavy, due also to its concrete structure.

The second floor is at the crucible upper level; at this floor run the charging and stocking machines and here are also located the control room and the lab. On the second floor are located transformers (3 single phase), capacitors and flexible connections both for power and water. Always on the second floor are the transformer oil coolers, placed on the outside of the building. On the third floor are the electrodes moving and slipping equippments and the electrode paste feeding system.

THE FURNACE

The crucible is not round, it has the same shape you may observe when dismantling an old furnace i.e. a kind of triangle with smooth corners.

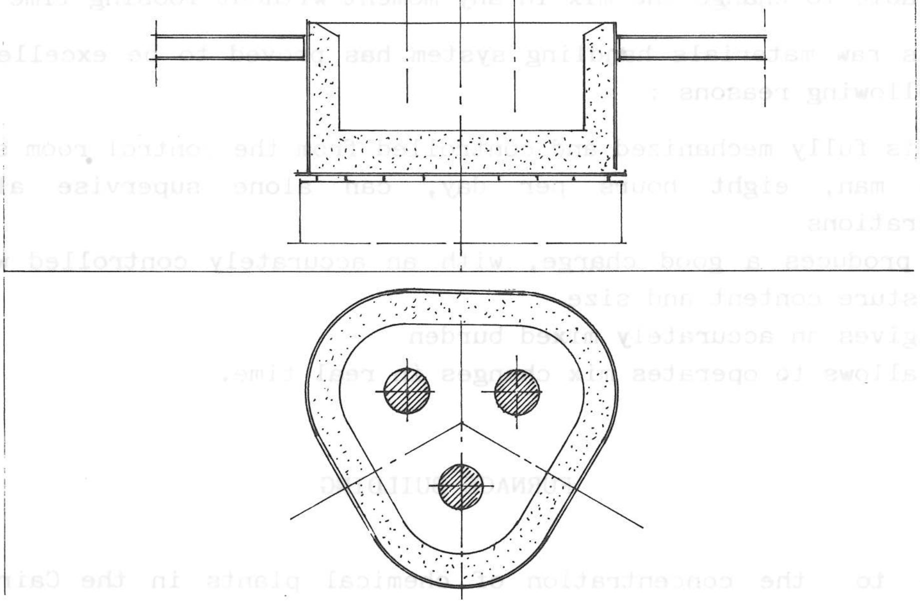

Fig. 3 Furnace body

The frame is made of steel plates of different thickness, streigthened by numerous vertical and horizontal ribs. The original wall lining consisted of four different layers :

- insulating material
- refractory concrete (chamotte+high alumina cement)
- 42% Al_2O_3 refractory bricks
- carbon blocks 600 mm thick

The bottom lining was instead made of two layers :

- 42% Al_2O_3 refractory bricks
- carbon blocks 1500 thick

This lining lasted more than 9 years and was changed in March 1982.

The new lining is pratically identical except for the wall thickness which was slightly reduced in order to help the furnace self lining process. The hearth surface is 58,5 square meters.

Two tapping holes for the metal are situated among the electrodes, the slag tapping hole is instead located under one electrode, one meter above the metal tapping holes level. Every tapping hole is naturally equipped with a drilling machine and a mud gun.

The electrodes are placed at the vertices of an equilateral triangle. The electrode pitch diameter can be varied from 3,00 m. to 4,20 m. This feature allows us to change rather drastically the power density in the reaction area and therefore to change the production to other alloys, if required. The electrodes have a diameter of 1400 mm. and are equipped with an eight clamps Demag clamping device. As metionned before all flexible connections are outside the furnace, at the transformers level. The current is brought to the clamps by straight copper pipes which pass trough the smoke-hood. Bus bars, clamps and clamp pressure rings are protected by water cooled stainless steel screens. The electrode holder too is made of stainless steel. The smoke-hood is made in concrete with high alumina cement and stainless steel reinforcing bars. Cooling water circulates in a pipe ring linking the furnace to an air cooler.

Great attention was given to the fume collecting system, which was designed so as to ensure a constant speed of fumes everywhere around the furnace; a moving chain screen is also being used.

The electrodes moving and slipping devices are operated by screws in order to avoid both the risk of rope tearing and the problem of oil leakages. This system has proved to be very effective and safe.

The three single phase transformers can work at a nominal apparent load of 22 MVA; the total active power can be as high as 15.5 MW since the power factor is close to 0.7. The transformer wiring design allows to switch the furnace on and off under load without moving the electrodes.

The furnace is controlled by an electronic control system supplied by Secheron which can work either at constant impedance or at constant current. We are using it the second way.

CONTROL ROOM

The control room is equipped with a set of instruments which indeed allows one single man to control all the plant and all the operations including the electric network, the raw material feeding and weighting system and all ancillary equippment.

CASTING SYSTEM

The casting system is very simple; it consists of two casting beds, made of cast iron, for the metal and of a water pool for the slag. The metal - up to 50 tons - is poured in the casting beds where it forms layers of about 2 sq.m. each and 150 mm thick. These layers solidify in about 30 - 40 minutes and are then taken to a bin by a crane with authomatic tongs which fit a steel pin dipped into the ferromanganese. The bin is equipped with a screening device which eliminates all fines coming from the casting bed. At this stage of the production the ferromanganese is sized about 250-300 mm and can be either sold as "tout-venant" or crushed into calibrated sizes.

The crushing plant, again very simple, is made of two large crushers which work in series. The crushed material is sieved according to the following four sizes (in mm)

0-3 3-10 10-50 50-150

and taken to four separated bins.

From these bins the material is directly delivered to the Customer, without any further handling. The fines too are sold which, in other words, means that fines are not remelted.

GAS CLEANING

At the very beginning the furnace was equipped with a low pressure wet scrubber which should have been able to reduce the dust content in the exhaust gases down to 80 mg/Ncm, the level required by the local regulation. As a metter of fact this figure was achieved only when the operating conditions inside the furnace where optimal. In the meantime however the local authority lowered the admitted dust content down to 30 mg/Ncm and we were therefore forced to install a dry bag filter despite the fact that the gas temperature was low and close to the dew point.

Together with De Cardenas we designed a simple and effective plant: a good insulation and an authomatically operated safety heating system prevent the gas from getting too close to the dew point. No gas cooling is necessary. In case of emergencies cold air is authomatically let in to prevent the bags from burning. The dust contents lower then 10 mg/Ncm.

The gas cleaner is made up of four groups of bags; three of them are sufficient to ensure normal operations, it is also possible to work with only two of them provided that the load is reduced to 10 MW.

The bags are cleaned with the "pulse air system" wich gives good results. The gas speed across the bags is about 1 m/min. the pressure drop is 80÷100 mm H_2O and the bags life is very long. (The firs set lasted 7 years). Power consumption is about 30 Kwh/ton of metal.

The dust is pelletized but not charged back into the furnace.

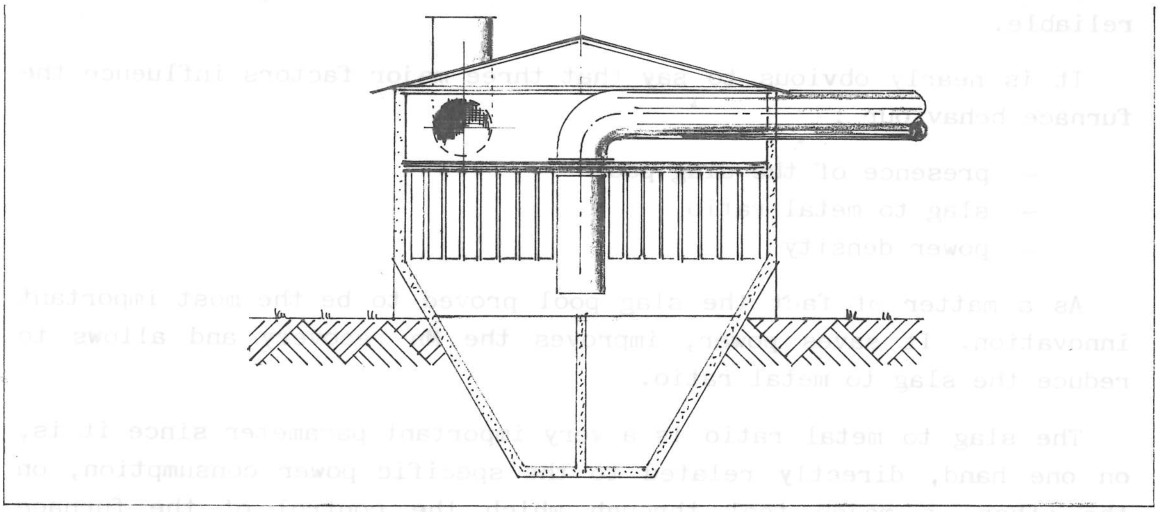

Fig. 4 Gas cleaning plant: schematic view

WORKING CONDITIONS

We started the furnace working without slag pool because, having no experience with the two tap process, we did not want to have at the same time the possible problems given by a new furnace and by a new process. Soon after we started working we had the pleasure and the luck of meeting Mr Yonemochi, who just retired, and Mr Tetsua Yamada.

We reached an agreement in order to get their assistance and Mr Yamada, who is still cooperating with us, started the two tap process.

We have been running this furnace for more than ten years now and over this period of time we have changed the working conditions a number of time.

We have operated :

- with or without slag pool
- with various slags (self fluxing, low or high Al_2O_3, high basicity, low or high MgO)
- under different loads (from 6 to 15,5 MW)
- with different tapping intervals (from 2 to 8 hours)
- with different electrodes distance
- with charges of different sizing

The furnace has proved to be, as desired, very flexible and reliable.

It is nearly obvious to say that three major factors influence the furnace behaviour :

- presence of the slag pool
- slag to metal ratio
- power density

As a matter of fact the slag pool proved to be the most important innovation. It saves power, improves the Mn recovery and allows to reduce the slag to metal ratio.

The slag to metal ratio is a very important parameter since it is, on one hand, directly related to the specific power consumption, on the other, a major tool through which the control of the furnace resistance can be obtained operating also on "recycled slag".

Power density, measured as KW per square meter of reaction area, must not exceed a certain value; when power density is higher than this value the open furnace really becomes the wild tool it is usually considered to be.

Other factors must be however taken into account. The slag composition is one of them and its influence is very important. We go as far as to say that the slag is the product and ferromanganese the the by product of this process. We have now come to think, however, that very different slag compositions can be equally satisfactory provided their basicity (considered as the ratio $CaO+MgO/SiO_2$) is high enough to ensure the presence of free MnO and that their melting point and viscosity are reasonable. An increase of the melting temperature and / or viscosity of the slag results infacts in higher tapping temperature, higher silicon content, narrowed reaction area and finally higher power and coke consumption.

As far as alumina content is concerned we stated that :

- it is absolutely not true that alumina content in excess of 14% slows down the manganese reduction
- a slag with a low alumina content (less than 8%) does not look to be a good one
- it is necessary, or convenient, to increase the alumina content when one wants to reduce the slag to metal ratio.

An other important factor is the sizing of the raw materials.

As far as coke is considered, the main problem is the conductivity of the charge; in order to control it we charge coke lumps of two sizes: 10/20 mm and 20/40 mm.

For the iron ore the problem is indirect reduction and it is therefore preferable to have it into small pieces.

When manganese ore and fluxes are concerned heat recovery is the main problem. The upper part of the crucible is nothing but an heat exchanger. We have all heard lots of ideas and projects, especially during the last years, concerning heat recovery inside and outside the furnace: rotary kilns, boilers shafts. But it is obvious that it is more economic, whenever possible, to recover the heat inside the furnace, in the process itself.

This means that great attention must be paied to the upper part of the crucible. In order to help the heat exchange the single lumps of material should have a high surface to volume ratio and the gas permeability of the charge should be such as to allow the output of the gases at the lowest uniform speed. Gas permeability is related to size distribution rather than to size. By working on size and size distribution it is therefore possible to achieve the best heat recovery and this takes place when the size of the lumps is small, so small that, in a closed furnace it could be dangerous.

As a matter of fact from many years we are crushing the Comilog ore which has been quite often, and at present is, our only ore. In order to improve the heat recovery it is also necessary to move from time to time the charge.

When the furnace is working under normal conditions the surface of the charge is only warm so that you can touch it with your hands (without gloves!).

TECHNICAL RESULTS

For many years, after some time spent to obtain a good knowledge of the furnace and of the process, we have been achieving the following average results :

Power consumption furnace	2050	Kwh/ton
" " total	2100	Kwh/ton
Manganese yield	82%	
Electrode paste consumption	7	Kg/ton
Coke (dry) consumption	340	Kg/ton
Slag production	500	Kg/ton
Minimum power consumption (monthly average)	1900	Kwh/ton
High alumina slag - alumina content	24%	

No fines remelting takes place.

Apart from storage in a covered store and crushing there is no treatment of the raw materials.

S A F E T Y

During ten years operation we had some few problems that could have involved safety problems.

We had twice important tapping problems without consequences neither for people nor for the plant because aside the furnace we have a large pool which can receive a large amount of molten material.

When we started working with the slag pool we had a serious problem: in the previous furnace conditions all around the furnace wall was formed a tick layer composed by hot ore fines still containing all the oxigen and probably also combined water.

The slag pool during its formation started eroding the foot of this layer making it fall into the furnace with sudden gas output. This phenomenon became more and more violent until finally it took the form of an explosion. The only consequence has been the output of the whole charge and the break of an electrode cut longitudinally into two pieces.

No other consequences to people or to the plant.

The partial output of the charge took place some other time, allways with no consequences.

MAINTENANCE

Ordinary maintenance requires less than one working day per month (8 hours).

Two major stops have taken place since the plant started the operations and each of them lasted about 40 days. The first stop was caused by overstocking and the second by the change of the crucible. Of course both stops where utilized for extraordinary maintenance mainly concerning clamps, water cooling system, and parts subjected to wear.

CONCLUSIONS

The decision to build an open furnace and to run it with the two tap process has proved to be a good one, since we are having the lowest possible costs, considering our geoeconomical situation.

Without entering a detailed comparison between our furnace and a closed one we can state that :

- Consumptions are very low
- Investments, depreciation and interest on investment are low
- Gas cleaning is cheap because of low investment, low power consumption and because water treatment is not needed
- The required manpower is about 3,2 hours per metric ton including administration
- Any physical composition of the ore can pratically be accepted when the size is not to large. Apart from eventual crushing no other treatmen is required
- The furnace is safe and easy to control

As a result should we decide to install to day a new ferromanganese plant we would still be in favour of an open furnace.

The size is not a problem because there is no reason not to reach higher power input.

We belive that it is still possible to decrease the investment acting on a further design semplification having to do with furnace building, raw material handling and casting hall.

We must recognize that this paper is a poor one, having nothing scientific: it is only the condensed report of our experience concerning a modern open electric furnace.

The following tables give an example of the standard charge and of the operating parameters.

1 - RAW MATERIALS ANALYSIS (%)

ITEM	Mn	(MnO_2)	Fe	SiO_2	Al_2O_3	MgO	CaO	T.C.	V.M.	CO_2	C.W.	P	H_2O
MOANDA	50,50	75,30	3,50	2,50	6,22	0,04	0,07				5,5	0,12	10,50
MILL SCALE			71,00	2,10	0,31	0,08	0,12						5,00
DOLOMITE				1,20	0,52	19,95	29,47			44,90			2,00
COKE				4,28	2,50			89,00					9,00
EL. PASTE								82,70	13,80				

2 - Fe Mn HC (Mn 75,5% - Si 0,2% - C 6,6%)
MATERIAL BALANCE FOR 1 TON OF METAL

2.1. CHARGE

ITEM	Kg Dry	T.Mn	O_2	Fe	O_2	SiO_2	Al_2O_3	MgO	CaO	T.C.	CO_2	P	C.W	H_2O
MOANDA	1798	908	498	63	33	45	112		1			2	99	190
MILL SCALE	145			103	35	3	4							6
DOLOMITE	160					2	1	32	47		72			3
COKE	320					14	8			285				29
EL.PASTE CASE	6			4						5				
TOTAL	2429	908	498	170	68	64	121	32	48	290	72	2	99	228
													327	

2.2. PRODUCTS

ITEM	Kg Dry	T.Mn	O_2	Fe	O_2	SiO_2	Al_2O_3	MgO	CaO	T.C.	CO_2	P	C.W.	H_2O
METAL	1000	755		165		4				66		1,8		
SLAG	483	148	43	4		59	119	31	44			0,2		
DUST	17	4		1		1	2	1	4	3				
Mn VAPOR	1	1												
EXHAUST GAS	488 Nm3		(455)		(68)					221	72		(16)	
H_2OVAPOR													(311)	
TOTAL		908	498	170	68	64	121	32	48	290	72	2	327	

SLAG COMPOSITION %

Mn	30.64
SiO_2	12,21
Al_2O_3	24,63
MgO	6,42
CaO	9,10

GAS COMPOSITION

CO_2	77,05%
Co	14,95%
H_2O	4 %

BASICITY = $\frac{CaO+MgO}{SiO_2}$ = 1,27

Mn Recovery $\frac{755}{908}$ = 83,15%

3.1 HEAT BALANCE

ITEM	Condition of Calculation	Kg	10^3Kcal	Kwh	Ratio %
Formation Heat of Mn_3C	$3Mn+C$ Mn_3C – 3,6 Kcal/mole	755	– 16,5	– 19,2	– 1,01
" " of Slag	– 120 Kcal/Kg	483	– 58,0	– 67,4	– 3,95
Combustion Heat	$C+O_2$ CO_2 –94,05 Kcal/mole	CO_2 667	–1425,7	–1657,8	– 87,25
" "	$C+½O_2$ CO –26,4 Kcal/mole	CO 91	– 85,8	– 99,8	– 5,25
TOTAL A			–1586,0	–1844,2	– 97,06

3. 2 HEAT BALANCE

ITEM	Condition of Calculation	Kg	10^3Kcal	Kwh	Ratio %
Sensible Heat of Metal	1350°C–25°C 0,237 Kcal/°C Kg	1000	315,0	366,3	19,28
" " of Slag	1400°C–25°C 370 Kcal/Kg	483	178,7	207,8	10,94
" " of Gas	150°C–25°C 0,382 Kcal/Nm^3	488	23,3	27,1	1,43
" " of Moisture	150°C–25°C 0,45 Kcal/Kg	311	17,5	20,3	1,07
" " of Mn Vapor	1350°C–25°C 6,8 Kcal/mole	1	0,1	0,1	–
" " of Dust	150°C–25°C 0,2 Kcal/Kg°C	17	0,4	0,5	0,03
Evapor.Heat of H_2O	H_2O_{liq} H_2O_{vap} 10,52 Kcal/mole	311	181,8	211,4	11,13
" " Mn	Mn_{liq} Mn_{vap} 53,7 "	1	1,0	1,2	0,06
Formation Heat of Fe_3C	3Fe+C Fe_3C 5,4 "	165	5,3	6,2	0,83
Decomp.Heat of $CaCO_3$	$CaCO_3$ $CaO+CO_2$ 42,85 "	CaO 47	36,0	41,9	2,21
" " of $MgCO_3$	$MgCO_3$ $MgO+CO_2$ 27,82 "	MgO 32	22,1	25,7	1,35
Reduction Heat of MnO_2	MnO_2 $MnO+½O_2$ 32,3 "	MnO_2 1355	503,0	584,9	30,78
" " of MnO	MnO $Mn+½O_2$ 92,0 "	Mn 756	1264,6	1470,5	77,39
" " of Fe_2O_3	Fe_2O_3 $2Fe+3/2O_2$ 196,3 "	Fe 77	135,0	157,0	8,26
" " of Fe_3O_4	Fe_3O_4 $3Fe+2O_2$ 259,5 "	Fe 88	135,8	157,9	8,31
" " of SiO_2	SiO_2 $Si+O_2$ 209,3 "	Si 2	14,9	17,3	0,96
" " of P_2O_5	P_2O_5 $2P+5/2\ O_2$ 370,0 "	P 1,8	10,7	12,4	0,65
" " of H_2O	H_2O $H_2+½\ O_2$ 68,3 "	H_2 1,7	58,1	67,6	3,56
TOTAL B			2903,3	3375,9	177,68
TOTAL B – TOTAL A			1317,3	1531,7	80,63

4. HEAT AND OTHER LOSSES

ITEM	Condition of Calculation	Kg	10^3Kcal	Kwh	Ratio %
Sensible Heat of Cooling water	$\frac{325^T \times 24^h}{165}$ (40°-42°C)	47.200	94,4	109,8	5,78
Radiation Heat of Furnace Top	150° - 25°C		9,4	10,9	0,57
" " Wall	170° - 25°C		87,3	101,5	5,34
" " Bottom	120°C-25°C		10,2	11,9	0,63
Transformer Loss			41,3	48,0	2,53
Secundary Conductor Loss			65,0	75,6	3,98
Other Losses			9,1	10,6	0,56
TOTAL			316,7	368,3	19,38

THEORETICAL POWER CONSUMPTION	1.531,7	Kwh
HEAT AND OTHER LOSSES	368,3	"
TOTAL POWER CONSUMPTION	1.900,0	"
FURNACE EFFICIENCY	80,6	%

5. GAS CALCULATION

a. $CO + CO_2$ AND TOTAL GAS

$\frac{221}{12}$ x22,4 = 412,5 Nm^3 (221 Kg of Fix Carbon from Tab. 2)

$\frac{72}{12}$ x22,4 = $\underline{36,6}$ " (72 Kg of CO_2)

449,1

ASSUMED $CO_2 + CO$ = 92%

TOTAL GAS 449,1/0,92 = 488 Nm^3

b. ASSUMED H_2 4% : 488 x 0,04 = 19,5 Nm^3

Kg. H_2 = $\frac{19,5}{22,4}$ x 2 = 1,74 Kg.

WATER = 1,74 x $\frac{18}{2}$ = 16 Kg.

H_2O MOISTURE 327-16 = 311 Kg.

KgO_2 = 16 x $\frac{16}{18}$ = 14 Kg.

c. RATIO CO/CO_2

$$\begin{cases} x + y = 221 \\ \frac{16}{12} x + \frac{32}{12} y = 455 + 68 + 14 = 537 \end{cases}$$

x = 182 Kg : CO_2 $\frac{44}{12}$ x 182 = 667 Kg = 340 Nm^3

y = 39 Kg CO $^{28}/_{12}$ x 39 = 91 Kg = 73 Nm^3

d. GAS COMPOSITION : CO_2 (340 + 36) / 488 = 77,05 %

CO 73 / 488 = 14,95 %

H_2 = 4 %