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A TECHNO-ECONOMIC ASSESSMENT OF LARGE AND SMALL FURNACES

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ABSTRACT

The ferro-alloy industry of the world has followed an exponential growth during the period from 1925 to 1980. Furnaces have increased in number as well as in size. It is predicted that the industry will continue to grow. The size and number of future installations are dependent on a number of factors which include the proposed types and grades of products, the volume of production, the quality of available raw materials, the existence or lack of an infrastructure and the quality and quantity of labour. The advantages and disadvantages of both large and small furnaces are discussed with reference to each of these factors.

The Meyerton Works of Samancor Limited is considered as a case study with respect to the arguments for and against large and small furnaces. Ten ferro-alloy electric furnaces varying in size from 3,8 MVA to 81 MVA are in operation at the plant. The older furnaces have been modernized over the years and meaningful comparisons can therefore be made among them. The furnaces are compared with respect to technology of design and operation, economy of scale and marketing strategy.

It is concluded that each situation is unique and that no universally applicable blue print can be provided. In future plasma technology could prove to be more advantageous than conventional arc furnace technology.

INTRODUCTION

Throughout the world, the increase in total ferro-alloy production capacity has followed an exponential growth during the period 1925, when the industry was in its infancy, to the beginning of this decade.

In South Africa, this growth has followed the world trend. The present day rated capacity of 1 255 MVA compared to the figure of 20,5 MVA in 1926 represents more than a sixty fold increase in approximately as many years - truly a spectacular achievement. The increase in capacity has come about in two ways : firstly by an increase in the number of furnaces and secondly, and of greater importance, by an increase in the average size of the installations. In 1942, the first two electric ferro-alloy furnaces were commissioned in South Africa. These units, rated at 3 MVA each, were used for the production of ferromanganese and silicomanganese. Today, forty years later, the largest unit in this country is the 81 MVA furnace of Samancor Limited at Meyerton. Furnace size has thus increased by a factor of twenty seven in terms of the transformer capacity. Today the number of furnaces is at least 54.

Initially, the ferro-alloy plants were located in the industrialized countries of the world. These highly developed countries could offer the necessary stimuli and factors of production to establish this industry : a ready demand for the product in the nearby steel plants, capital to finance these capital-intensive ventures, skilled manpower to manage and operate the plants, an existing infrastructure to provide communications and transport as well as in some instances, cheap power in the form of hydroelectricity. Raw materials, particularly the ores, were usually imported. However, as transport was then reasonably cheap, this was not seen as a major deterrent in deciding on the location of these plants.

Recently, the increase in alloy production capacity and the increase in production have largely shifted to the ore producing countries. To illustrate this statement, table 1 and figure 1 reflect the production of ferromanganese (including silicomanganese) and ferrochrome in selected countries during the priod 1975 to 1980.

In 1975, world production of ferromanganese amounted to 6 206 000 t. In 1980 this figure was 6 525 400 t, an increase of only 319 300 t or 5,1% over the period. Although the total production thus showed little growth, there was a marked swing to the ore producing countries at the expense of the traditional producing countries.

World production of ferrochrome rose from 2 014 400 t in 1975 to 2 582 300 t in 1980, an increase of 28% over 5 years. Yet countries like Brazil, Turkey and South Africa increased their output by 66,7% 411,1% and 192,7% respectively.

The increase in the cost of energy which brought about this trend, influenced both the production and the transportation of the materials. In terms of overall energy utilization, it is more expedient to transport one tonne of alloy than to transport two or more tonnes of ore over the same distance.

This introduction has served to highlight the growth in total ferro-alloy capacity and size of furnace as well as the change in geographical location of the plants. It can confidently be stated that the ferro-alloy industry will continue to grow and that new furnaces will be planned and constructed to cope with the growing demand.

One important decision which confronts the would-be plant owner, is what size of plant to install.

This paper briefly discusses some of the factors which could influence the decision without trying to provide a blue print and relates the experience of the Meyerton Works of Samancor Limited where a wide spectrum of furnace sizes is to be found.

FACTORS RELATING TO SIZE OF PLANT

When planning one or more furnaces either on a green field site or as part of an existing plant, the size of furnace(s) is probably the most important decision that has to be taken. Furnace size is broadly defined as the physical dimensions of the unit as well as the electrical transformer rating, which are interrelated for a given product.

A number of alternatives are available : whether to opt for one large furnace or a number of smaller units. The final configuration will be influenced by the following factors:

1 Product range
2 Product grades
3 Volume per type and grade of product
4 Raw materials
5 Infrastructure
6 Labour

1 Product range

The main product or products to be produced have an important bearing on the design, number and size of furnaces required. It seems an obvious statement yet invariably during the life of a plant designed specifically for one product, feasibility studies are undertaken to determine whether the plant will be suitable for another product. If the necessary flexibility is not incorporated into the initial design, it may prove technically and economically unattractive to switch to another product without costly modifications. The usual practice in South Africa is to produce only one type or at most, two types of tonnage ferro-alloys in one plant. Chrome and manganese alloys are normally not produced simultaneously in a multi-furnace plant for fear of contaminating raw materials and products. In a number of plants, ferrosilicon is produced together with either ferrochrome or ferromanganese. However, unless completely separate facilities per product are provided for raw materials handling and finished products crushing and screening, contamination is always a threat. According to Murphy's law if anything can go wrong, it will! Thus ideally each product requires a separate furnace building and infrastructure.

2 Product grades

Unless different technology is involved, producing different grades of a specific type of ferro-alloy on the same furnace does not present any problems. It is important to decide whether the different grades are to be produced concurrently, or whether sufficient time is available to schedule consecutive runs per grade on the same furnace. Off-grade material is produced during the change-over from one grade to another and this must be remelted. If the situation warrants it, different furnaces for different grades of product within a common infrastructure should be provided.

3 Product volume

The type and grade of product required simultaneously determines the minimum number of furnaces. The production volume per category in turn determines the electric power necessary to achieve this output. For a conventional, submerged arc 3-electrode furnace producing manganese, chrome or silicon ferro-alloys, the upper power limit today is in the region of 50-60 MW. Given the specific smelting electric energy consumption per product, the maximum output per furnace and thus the minimum number of furnaces per type and grade of product can be calculated. Of course, the same tonnage can be produced from a number of smaller units. The economy of scale of an actual multi furnace plant with different sized furnaces will be discussed in detail.

4 Raw Materials

Producers in the industrialized countries are able to import and blend ores to suit their requirements. Plant design and furnace size are thus not entirely dependent on raw material quality, as different raw materials may be purchased to suit the equipment. However, with the shift in ferro-alloy production to the ore producing countries, the producer has little choice in the selection of ores, as he is limited to the type of ore found in that particular country. In some instances where the same company both mines and smelts the ore, the choice is even smaller. A number of companies also mine the fluxes and coals themselves and are therefore totally restricted to their own raw materials. The properties of these raw materials have a direct bearing on the design of the plant and the size of the furnace. An example of this is to be found in South Africa, where the nature of the friable Transvaal chromite is such that agglomeration or pretreatment of the ore is required to allow for maximum exploitation of the mined ore in large furnaces. Various charge chrome producers have committed themselves to different routes of ore pretreatment for use in large furnaces. Samancor, with 48 MVA furnaces, has chosen to briquette chromite fines. This is also the case with MSA who operate 30 MVA furnaces. However, in December 1981 this company announced its intention to construct a 10,8 MVA transferred arc plasma furnace due for commissioning in September 1983. This will enable them to smelt untreated chromite fines apart from the other advantages of lower capital outlay, higher chrome recovery and minimal gas cleaning. Undoubtedly, this development will be followed with great interest by all ferro-alloy producers.

CMI has elected to pelletize and prereduce chromite fines according to the Showa Denko process for their 32 MVA furnaces. Tubatse Ferrochrome uses partly washed, partly run-of-mine ore in 30 MVA furnaces based on techniques developed by Union Carbide.

Plant design and furnace size are thus greatly influenced by raw material properties.

5 Infrastructure

An existing infrastructure or lack of it, will influence the size of furnace to be erected. If a furnace is erected on a green field site, economy of scale will be of major importance and in general, the larger furnace should be the best choice. Where a furnace is planned as an extension to an operating plant, factors such as flexibility of product range and grade, as well as raw material preparation cost become important. In this instance, two smaller furnaces could well prove more advantageous than one large furnace.

6 Labour

Labour costs differ from one country to another. The cost of labour in an industrialized country with established labour organizations is higher than in less developed countries. In South Africa, unskilled labour has generally been regarded as a cheap commodity compared to labour in European countries for instance. However, after the two tier gold price system was introduced in 1971, the wages of unskilled workers have increased at a faster rate than those of their skilled counterparts. Labour costs have at times risen faster than the general rate of inflation and thus labour has become more expensive in comparison with some of the other production cost factors. When deciding on the size and number of furnaces, labour cost per unit of production will become an increasingly important consideration and will tend to favour the construction of larger furnaces and more mechanised and automated plants requiring fewer manhours per tonne of product.

Furnaces have not only become bigger but also more sophisticated. Electronics has revolutionized furnace instrumentation and control. These automated plants require highly skilled maintenance and operating personnel. Thus the level of education required to staff a ferro-alloy plant has also risen. This is more critical for a big furnace than for a smaller production unit. Small furnaces respond more quickly to changes than larger furnaces and thus the effects of a mistake in e.g. burden composition are not as critical. Therefore a smaller furnace can operate more successfully without intricate instrumentation and control equipment than the larger unit, and as a result of this, fewer skilled artisans and engineers are required. In countries where labour is relatively cheap and mostly unskilled and the supply of labour outstrips the demand, a strong argument can be put forward for smaller less sophisticated furnaces compared to fewer bigger more sophisticated units.

A CASE STUDY

The Meyerton Works of Samancor Limited will be considered as a case study for the preceding arguments with respect to the relative advantages and disadvantages of large and small furnaces. The history of the plant has been well documented in a number of publications.

At the time of writing, there are fourteen electric furnaces at the Works of which ten normally produce either high carbon ferromanganese or silicomanganese in different grades. As far as could be established, it is the largest single manganese ferro-alloy smelting works in the world with a total electric power demand in excess of 200 MW. Over the years, most of these furnaces have been extensively modified, uprated and modernized. The present configuration bears little resemblance to the original, and thus meaningful comparisons can be made among the furnaces regarding i.e. efficiencies, relative production costs and raw material preparation. The furnaces have been grouped into seven classes in ascending order of size. The main furnace dimensions and ratios are listed in table 2. Table 3 contains details of the electrical design and operating characteristics while table 4 indicates the relative cost of production for the same type and grade of product.

The following factors will be considered :

1 Technology of design and operation
2 Economy of scale
3 Marketing strategy

TECHNOLOGY OF DESIGN AND OPERATION

1 Raw Materials

Raw materials are the crux of ferro-alloy production. Producers in the ore-producing countries have comparatively little choice in the selection of raw materials. Production personnel at Meyerton have Mamatwan and Wessels manganese ores at their disposal. Similarly, fluxes such as quartzite, dolomite and serpentine are also owned and mined by the Group. Coke is procured from the major coke producer in the country. However, a variety of bituminous coals are available from coal trading companies.

Raw material preparation on the other hand, can be tailored to suit the requirements of a particular furnace. At the mines, the ores are crushed and wet-screened to produce the required size ranges. Mamatwan is available in two size fractions i.e. 63 x 25 mm and 25 x 6 mm while Wessels is currently available as 63 x 6 mm. Lumpy Mamatwan ore is destined for the group 6 and 7 furnaces while the finer fraction goes to the smaller furnaces in groups 1 to 5. The raw materials for group 7 furnace are bedded and screened at 10 mm prior to proportioning. The -10 mm fraction is again screened at 6 mm and the 10 x 6 mm fraction used in group 4 and 5 furnaces while group 1, 2 and 3 furnaces use the -6 mm fraction as part of the ore feed. The -10 mm coke and coal are sold to local brickworks. The -10 mm quartzite is used in the concrete batching plant.

For group 6 furnaces, raw materials are all screened at 6 mm. Coke and coal fines are again sold. Quartzite fines are used for concrete and ore fines are used partly in group 1, 2 and 3 furnaces from time to time.

The full utilization of raw materials, while not compromising on preparation, would not be possible without both large and small furnaces. Raw material preparation is essential for optimal performance in large furnaces, but is not essential for smaller furnaces. The physical characteristics of the raw materials are thus an important consideration in the choice of furnace size.

2 Electrodes

Stable furnace operation can only be achieved if furnace availability is high. An electrode break on a large closed furnace can disrupt furnace operation and reduce production for at least two weeks. A sound electrode management policy is essential to minimize the risk of electrode breaks. Smaller electrodes below 1,5 m in diameter are less prone to breakages under the same conditions than larger electrodes. Paste quality, casing design and manufacture as well as electrode slipping rates are more crucial for group 6 and 7 furnaces than for the others. Special low ash Söderberg paste is used in these electrodes and casing design and materials of construction have been developed to produce the best possible electrodes. Slipping rates and liquid paste levels are carefully controlled with thermocouples. Nevertheless, planned stoppages never exceed six hours for fear of losing electrode tips.

Group 1 to 5 furnaces on the other hand, operate satisfactorily on high ash paste. Electrode casings are also made to much larger tolerances. Slipping rates and the duration of furnace stoppages are not as critical either.

Although the burn-off rate per MWh is less for the large electrodes, the total electrode cost per unit or production is greater than for the smaller electrodes. This, and the greater likelihood of electrode breaks and the slower recovery after a break, favour smaller electrodes and therefore smaller conventional furnaces.

3 Furnace Control

Furnace control can be defined as a strategy which leads to the attainment of desired product quality at maximum stable furnace load. It starts with the selection, preparation, sampling, analysis and proportioning of raw materials to ensure that variations in quality are minimized and compensated for. A pretreatment system can be common to both large and small furnaces. Similarly, furnace instrumentation and control equipment are not peculiar to a specific size of furnace, although the capital required for such equipment would be virtually identical in both instances and thus not justified for small furnaces.

Providing that both large and small furnaces are fed with identical raw materials and have the same instrumentation and control equipment, large furnaces, by virtue of the bigger active crucible and working volume, are inherently slower to respond to change and exhibit less of a material plug flow pattern and more of a stirred reactor flow pattern than smaller furnaces. An indication of residence time for manganese ore for furnaces of different sizes (18 MVA and 75 MVA) is given in figure 2. It can be seen that the mean residence time for the small furnaces is 6,75 hours while it is 20,5 hours for the large furnaces. Also, the curve for the large furnaces exhibits a long tail which indicates that mixing takes place and that a metal inventory is retained in the furnace. This is a result of the different tapholes for metal and slag and the 300 mm difference in elevation between furnace hearth and metal tapholes on the large furnaces. The effect on product quality is evident in table 5 where it is shown that both HC Fe Mn and Si Mn of a more consistent grade are produced on the large furnaces and also that the mean lies closer to the minimum of the element specification : 65% Mn and 18% Si for Si Mn and 76% Mn and 78% Mn respectively for the two HC Fe Mn furnaces. This implies that fewer mix corrections are required on the large furnaces and a more economical raw material blend can be used. A further example of the difference in product quality is given when comparing figure 3 to figure 4 where histograms illustrate silicon distribution for group 2 and group 6 furnaces.

Furnace stability is achieved when furnace power and slag analysis remain constant. Furnace resistance and slag basicity have therefore been selected as indices of furnace stability. Table 6 shows that in terms of these indices, large furnaces are more stable than small furnaces. However, the comparison of resistance between the group 5 and group 7 furnaces is not strictly relevant, as the big furnace is equipped with a more advanced electrical controller.

Large furnaces have the advantage over small furnaces of better control by virtue of a more constant product analysis and more stable operation.

4 Specific energy consumption

A number of investigators have shown that the specific energy consumption is lower on a big furnace than on a small furnace when producing the same type and grade of product. This trend is also evident for the Samancor furnaces. The furnaces in groups 1 to 5 have a higher energy consumption than group 6 which in turn uses more electricity than the group 7 furnace to produce a tonne of product.

The reasons are as follows :

Heat loss through the furnace hearth and side walls accounts for 1,87% of energy input on group 1 to 5 furnaces, while the corresponding figures for group 6 and 7 furnaces are 1,47% and 1,38% respectively.

Secondly the metal mass per tap increases with increase in furnace size from 4t/tap for group 1 to 3 furnaces to 40t/tap for group 7 furnace. Metal lost as ladle skulls and runner scrap thus account for a greater percentage of the total production on the small furnaces than on the larger furnaces.

Finally, the large furnaces operate on a lower slag to metal ratio without forfeiting furnace stability or electrical resistance. This is made possible by the deeper furnace crucible and the different elevations of metal and slag tapholes.

Contrary to the small furnaces where slag is recycled to the furnace to maintain a minimum slag to metal ratio of 0,75 for HC Fe Mn and 1,3 for Si Mn to increase the electrical resistivity of the charge and thereby increase the power, no slag is recycled to the large furnaces. Raw material blends are purposely chosen to minimise the mass of slag produced per tonne of metal and this can be as low as 0,4 for HC Fe Mn. The frequency of slag tapping is adjusted according to the calculated slag : metal ratio and as a result, slag is retained in the furnace instead of being recycled to the furnace. The lower slag production leads to an increase in manganese recovery. The deeper furnace crucible also allows for better heat exchange between off-gas and raw materials. Off-gas temperatures are lower and overall energy utilization is improved. Dust and manganese vapour losses are minimized by the deeper material charge in the large furnaces through filtration and condensation. This also increases the manganese recovery and reduces the load on the dust cleaning equipment.

Large furnaces are more energy efficient and achieve higher recoveries than small furnaces.

ECONOMY OF SCALE

In a free enterprise system, the object of any entrepreneur is to maximise profits, or alternatively, to minimize losses where profit/loss is defined as the positive/negative difference between selling price and production cost multiplied by the production volume. Under free market conditions with a number of producers in the market, the individual producer has no control over the selling price. Rather, the selling price is determined by the market supply/demand relationship for that commodity.

Unless the individual producers combine forces to effectively form a monopoly or even an oligopoly, thus enabling them jointly to manipulate the selling price of their products, these producers can only control the volume of their product or, to a lesser extent, their cost of production. Both production volume and production cost are directly related to profits.

The effect of production volume on production cost at the Meyerton Works is evident from table 4 where the relative production cost per unit of production is given for the different furnace groups for the same type and grade of product.

Production costs albeit relative production costs are sensitive and classified information. Therefore, trends only can be indicated without reference to comparative figures. Ore costs increase with increase in furnace size and then decrease for group 6 and 7 furnaces as a result of the better recovery of manganese from ore to alloy. Total reductant cost increases with furnace size because of the greater usage of coke relative to coal. Coke produces a more stable carbon bed in the furnace than coal but the difference in price between coke and coal is a great incentive to use more coal. The cost of raw material screening losses increases substantially with furnace size. The overall effect is an increase in total raw material cost per unit of production with increasing furnace size.

Electrode cost rises in a step function between groups 1 to 5 and groups 6 to 7 furnaces. The reason for this can be found in the more stringent specifications for both Söderberg paste and electrode casings. However, these expensive electrodes on the large furnaces have virtually eliminated electrode breaks.

The cost of tapping materials decreases with increase in furnace size because more metal is tapped at a time on the big furnaces.

The cost of electrical energy is also lower for larger furnaces. When the variable costs are added together, small furnaces have the advantage of a lower cost per unit of production.

This advantage is completely reversed where the fixed costs are concerned. Fixed costs account for a significant fraction of the total costs and as a result of the lower fixed costs, total production costs are about twenty five percent higher on the smallest furnace compared to the largest furnace.

Thus, despite more expensive raw materials and electrodes, large furnaces have an overwhelming advantage over small furnaces because of the economies of scale.

MARKETING STRATEGY

Marketing strategy can be defined as the methods by which a company sets out to achieve its objectives in terms of its product range, market penetration, pricing policy and profit policy. Plant design should be tailored to cater for the vagaries of a dynamic market and consequently an adaptable marketing strategy is necessary to enable the producer to optimise profits under constantly changing market forces. In a depressed market with poor demand for products, outputs are reduced and production costs minimized. In a buoyant market where demand outstrips supply, outputs are maximized even at the expense of an increase in production costs.

Pricing and profit policies are not directly related to plant design as opposed to product range and market penetration where the number and size of the furnaces determine to what extent these objectives can be met in a changing market.

The Meyerton Works of Samancor Limited is a good example of a flexible and versatile plant for producing tonnage manganese ferro-alloys. Flexibility improved as larger furnaces were built and older, smaller furnaces modernized. The plant is well suited to produce a range of alloys at different levels of production and affords top management sufficient versatility to implement their marketing strategy. The large furnaces of groups 6 and 7 produce significant tonnages which serve as a springboard to increase market penetration if and when deemed necessary.

The smaller furnaces of groups 1 to 5 afford the flexibility to offer a comprehensive range of types and grades of alloys while the infrastructure allows for preparation of the product in any desired size range.

CONCLUSIONS

The optimum configuration of a new production facility is dependent on a number of factors. No universally applicable solution can be provided.

Rather, the specific elements of production must be analysed to arrive at a unique solution for each situation. Depending on the market strategy of the company, a tonnage ferro-alloy plant should be sufficiently flexible to produce a range of alloys while at the same time, the base load should be produced by large furnaces with their advantage of economy of scale.

It is the opinion of the writer that Samancor has taken the correct decision in building the large furnaces of the seventies. Future expansion will depend on the growth of the market. It may well transpire that the next generation of furnaces will not be conventional arc furnaces and that the small arc furnaces at the Meyerton Works may be phased out.

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TABLE 1

PRODUCTION OF FERROMANGANESE AND SILICOMANGANESE (in '000t)

	1975	1976	1977	1978	1979	1980
Australia	49,9	64,5	94,4	96,1	96,1	99,5
Belgium	115,0	103,6	74,2	75,9	93,0	65,6
Brazil	126,1	162,3	204,1	224,0	271,2	269,0
France	509,8	471,7	479,7	503,2	552,8	554,6
Germany	200,8	190,6	193,2	168,9	258,8	227,7
India	145,1	178,7	195,9	223,1	207,7	177,7
Japan	1 276,1	1 207,0	1 035,9	901,0	1 096,5	1 041,0
Mexico	55,3	71,6	127,0	140,6	155,1	155,0
Norway	504,1	534,4	442,7	409,0	531,5	450,0
South Africa	351,5	371,2	425,0	510,8	550,0	620,0
United States	652,3	554,8	411,5	375,9	437,3	342,6

PRODUCTION OF FERROCHROME (in '000t)

	1975	1976	1977	1978	1979	1980
Brazil	52,8	65,6	66,0	62,0	84,0	88,0
France	100,0	102,0	101,0	97,3	92,3	50,0
Germany	62,0	97,0	71,0	53,0	48,0	40,0
Japan	526,9	506,5	426,6	283,9	381,7	426,9
Norway	28,0	32,0	23,0	15,0	12,0	11,0
South Africa	246,0	302,0	390,0	533,0	695,0	720,0
Turkey	9,0	10,0	11,2	30,0	33,4	46,0
United States	155,7	177,1	182,1	159,4	224,0	192,3

Source : Ferro Alloy Statistics 1975 - 1980 Volume I H.G. Pariser

TABLE 2

FURNACE DIMENSIONS

FURNACE GROUP		1	2	3	4	5	6	7
Shell diameter (SD)	(m)	6,700	7,315	8,400	9,830	9,840	15,500	15,500
Shell height	(m)	4,090	3,960	3,850	4,235	4,235	7,123	8,200
Crucible depth	(m)	2,565	2,435	2,536	2,535	2,535	5,020	5,700
Hearth area	(m^2)	14,320	15,975	27,247	42,776	47,051	124,690	124,690
Crucible volume	(m^3)	45,115	49,208	72,677	111,702	123,544	625,944	710,733
Electrode diameter (ELD)	(m)	0,781	0,890	0,890	1,092	1,270	1,900	1,900
Pitch circle diameter (PCD)	(m)	2,100	2,400	2,440	3,124	3,683	5,426	5,485
Electrode centre to centre (ELC)	(m)	1,818	2,078	2,113	2,705	3,190	4,700	4,750
Electrode face to face (ELF)	(m)	1,037	1,188	1,223	1,613	1,920	2,800	2,850
Centre furnace to centre elect.	(m)	1,050	1,200	1,220	1,562	1,841	2,713	2,742
Electrode face to crucible face (EL-CR)	(m)	0,694	0,610	1,280	1,582	1,394	2,637	2,607
PCD/ELD		2,688	2,696	2,741	2,860	2,900	2,855	2,886
EL-CR/ELF		0,669	0,513	1,046	0,980	0,726	0,942	0,914
ELF/ELD		1,328	1,335	1,374	1,477	1,512	1,473	1,500
PCD/SD		0,313	0,328	0,290	0,317	0,374	0,350	0,353
Taphole level above hearth-metal	(m)	0	0	0	0	0	0,300	0,500
-slag	(m)						1,300	1,500

TABLE 3

FURNACE ELECTRICAL DESIGN AND OPERATING PARAMETERS

FURNACE GROUP		1	2	3	4	5	6	7
Transformer rating	(MVA)	3,8	7,5	10,0	10,0	18,0	75,0	81,0
Apparent power	(MVA)	4,46	8,91	10,71	11,60	17,35	74,25	69,16
Real power	(MW)	3,98	7,35	8,50	9,25	14,15	39,50	42,00
Reactive power	(MVAr)	2,01	5,04	6,52	7,00	10,04	62,81	54,95
Primary voltage	(kV)	6,60	11,45	11,45	11,45	11,45	33,00	33,00
Primary current	(A)	390	450	540	585	875	1300	1210
Secondary voltage (EL-EL)	(V)	81	130	140	149	179	330	300
Secondary current	(kA)	32,0	39,5	44,5	45,5	56,0	130,0	133,0
Resistance	(m.ohm)	1,30	1,57	1,43	1,52	1,50	0,78	0,79
Reactance	(m.ohm)	0,65	1,08	1,10	1,15	1,07	1,24	1,04
Impedance	(m.ohm)	1,46	1,90	1,80	1,91	1,84	1,47	1,30
Power factor		0,892	0,825	0,794	0,797	0,816	0,532	0,607
Electrode current density	(A/cm^2)	6,7	6,3	7,2	4,8	4,4	4,59	4,69
Hearth thermal load	(kW/m^2)	277	460	312	216	301	317	337
Optimum reaction zone (ORZ)	(m^2)	10,48	13,69	14,16	23,20	32,26	70,04	71,53
ORZ/Hearth area		0,732	0,857	0,520	0,542	0,686	0,562	0,574
ORZ thermal load	(kW/m^2)	380	537	600	399	439	564	587

Optimum reaction zone = $3 \left(\pi \times \frac{(1,16\ \mathrm{ELC})^2}{4} \right)$ where ELC = electrode centre to centre.

TABLE 4

RELATIVE PRODUCTION COST

FURNACE GROUP	1	2	3	4	5	6	7
Total production costs	1 269	1 189	1 142	1 135	1 091	1 028	1 000

TABLE 5

COMPARISON OF PRODUCT QUALITY

1 SILICOMANGANESE

	% Mn		% Si		% C	
FURNACE GROUP	2	6	2	6	2	6
Mean	65,69	65,29	18,43	18,26	1,30	1,190
Maximum	67,0	66,9	19,9	19,9	1,66	1,45
Minimum	64,8	64,4	15,4	16,9	0,91	0,95
Variance	0,221	0,179	0,633	0,375	0,021	0,015
Standard deviation	0,470	0,423	0,796	0,612	0,144	0,121

2 FERROMANGANESE

	% Mn	
FURNACE GROUP	5	7
Mean	76,57	78,31
Maximum	77,7	78,9
Minimum	74,4	77,6
Variance	0,313	0,060
Standard deviation	0,560	0,245

TABLE 6

COMPARISON OF FURNACE STABILITY

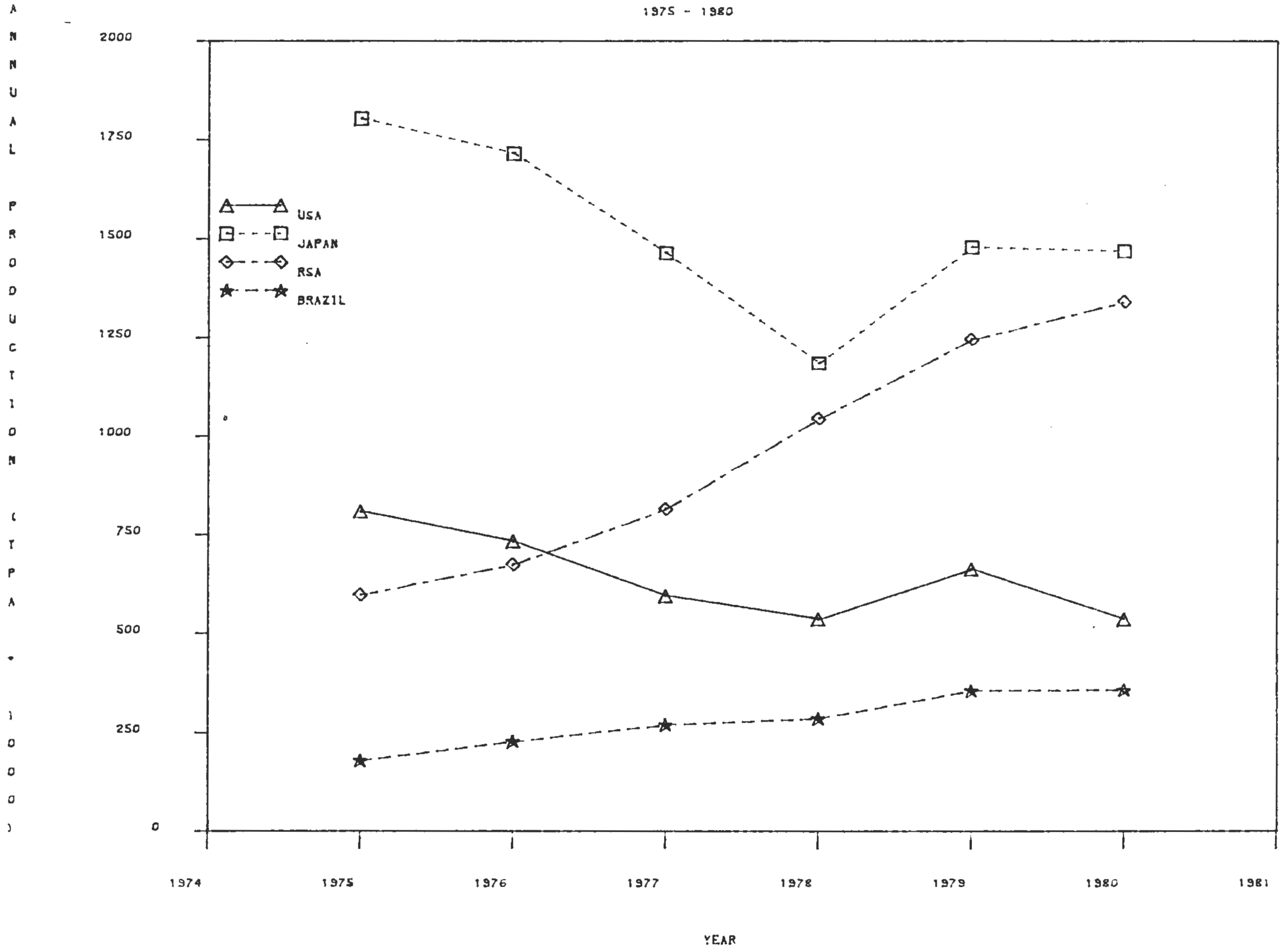
1 SILICOMANGANESE

Furnace Group	RESISTANCE (m.ohm) 2	RESISTANCE (m.ohm) 6
Mean	1,540	0,780
Maximum	1,65	0,86
Minimum	1,36	0,67
Variance	0,0043	0,0012
Standard deviation	0,066	0,035

2 FERROMANGANESE

	SLAG BASICITY		RESISTANCE (m.ohm)	
Furnace Group	5	7	5	7
Mean	1,270	1,200	1,600	0,770
Maximum	1,43	1,26	1,97	0,86
Minimum	1,20	1,16	1,30	0,64
Variance	0,0018	0,00053	0,0087	0,0013
Standard deviation	0,043	0,023	0,093	0,036

FIGURE 1



PRODUCTION OF FEMN SIMN & FECR

1975 - 1980

FIGURE 2 MANGANESE ORE RESIDENCE TIME GROUP 5 VS GROUP 6 FURNACES

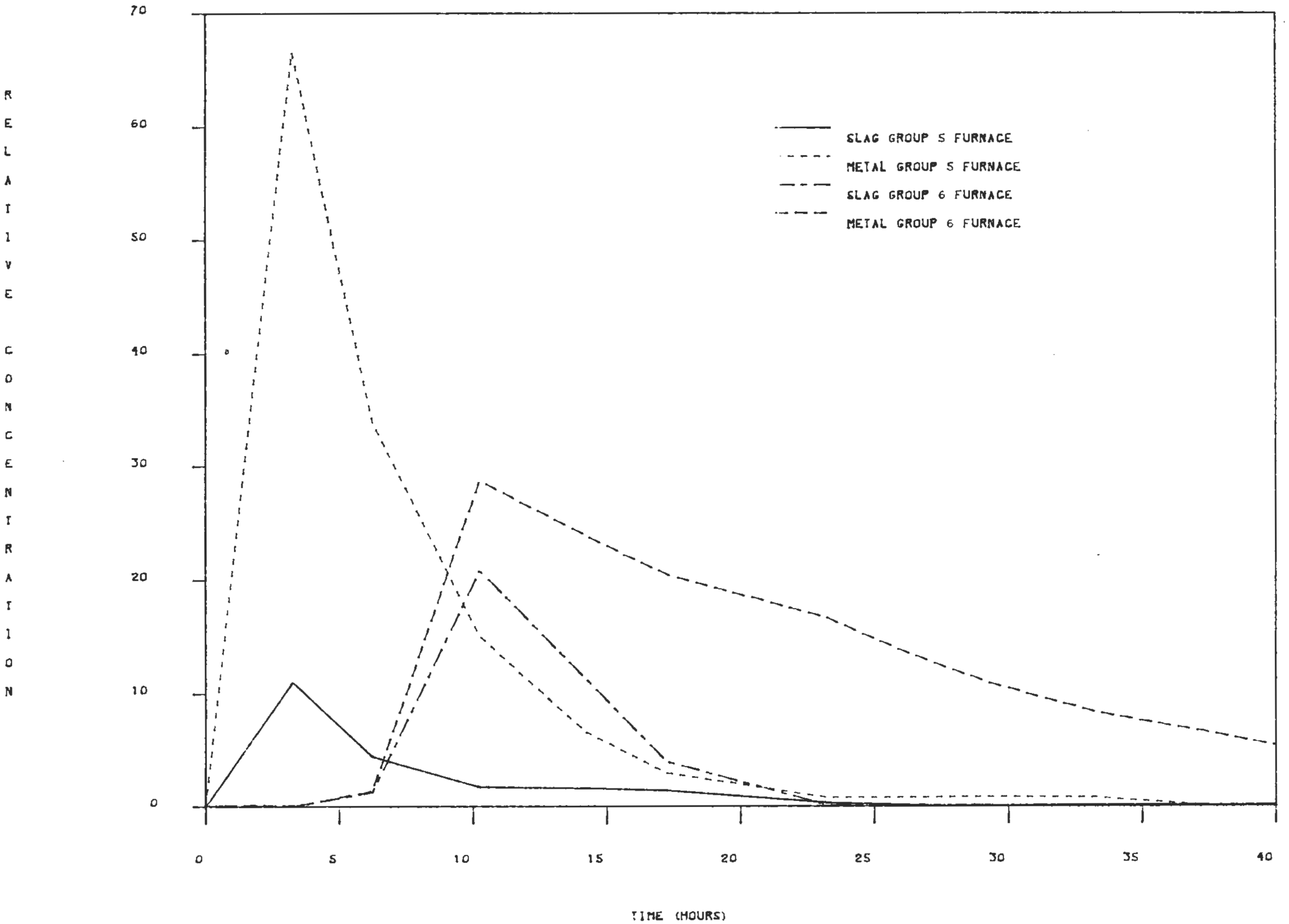


FIGURE 3

FREQUENCY DISTRIBUTION % SI GROUP 2 FURNACE

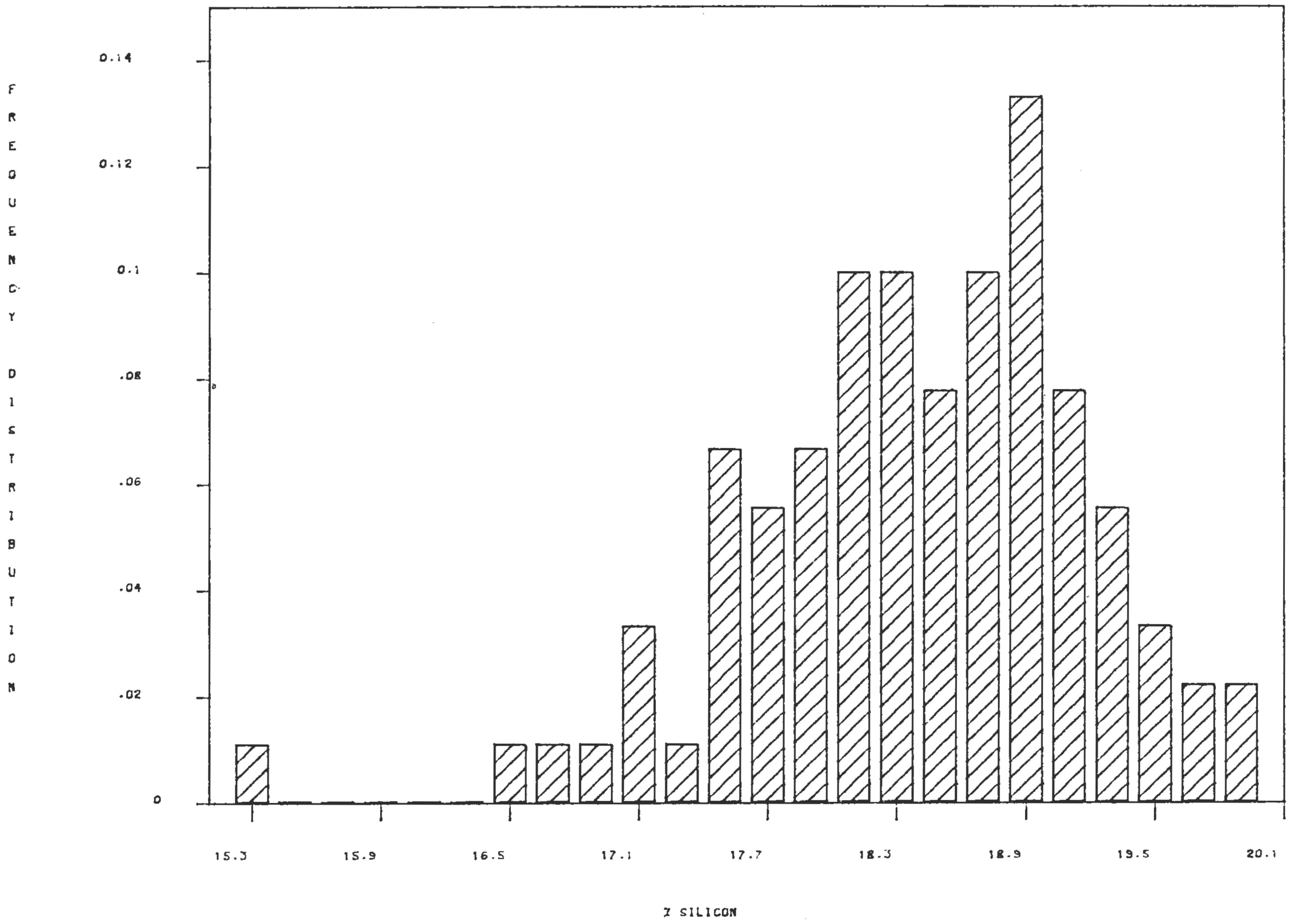


FIGURE 4

FREQUENCY DISTRIBUTION % Si GROUP 6 FURNACE