

# Trends in Ferro-alloy production

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## SYNOPSIS

New trends and developments in the production of ferro-silicon, ferro-manganese and ferro-chrome alloys are discussed, with emphasis on the general trend to the adoption of large production units. Problems which arise, both of a metallurgical and an electrical nature, due to the use of large electric furnaces, are outlined with specific reference to the limitations imposed by the power carrying capacity of Söderberg electrodes, the furnace resistance and the furnace reactance. The implications of combining high resistance within the furnace with good metallurgical operating conditions are illustrated by considering the production of ferro-silicon and ferro-manganese. The possibility of replacing electric furnaces used for ferro-manganese production, by large low shaft blast furnaces using oxygen enriched blast, is mentioned. The continued use of small electric arc furnaces for ferro-chrome production is also mentioned, and is ascribed to lack of ore suitable for treatment in large furnaces. Agglomeration of chromite ores appears to be a possible answer to this problem.

## INTRODUCTION

Major developments are afoot all over the world in the field of ferro-alloy production. Because it is geared very largely to the demands of the alloy steel industry, ferro-alloy production is rising at a much faster rate than that of the steel industry in general. As a result countries which a decade ago did not contemplate entering the ferro-alloy industry are now actively engaged in production.

Ferro-alloy production has had a relatively long history in this country, but the past decade has seen a remarkable expansion in this field, particularly in the ferro-chromium and the ferro-chrome-silicon alloys. I recently undertook an extended tour of ferro-alloy plants in Europe and Japan, and therefore had the opportunity of seeing something of the developments which are proceeding rapidly overseas, and of comparing and contrasting these with developments in this country.

I should like to discuss the new trends and developments in the production of ferro-silicon, ferro-manganese and ferro-chrome alloys, all of which are of special interest to us in South Africa.

As is the case with all pyrometallurgical industries, the general trend in ferro-alloy production is the adoption of very large units to effect greater economy in labour, savings in depreciation and enhanced production.

The undoubted advantages of these much larger units are attended, as is almost inevitable, by certain disadvantages, some of which were rather difficult to foresee. Both the electrical and the metallurgical aspects of ferro-alloy production are involved in the problems attending the use of the larger units as I will now attempt to show.

## ELECTRICAL CONSIDERATIONS

### Smelting Load

Assuming that the current carrying capacity of an electrode to be  $I$  and the resistance from the electrode to some neutral point in the furnace to be  $R$ , then the smelting load  $W_1$  submitted by that electrode is

$$W_1 = RI^2$$

and the total load in the case of 3 electrodes:

$$W = 3RI^2$$

where  $W$  = smelting power.

The furnace load is in other words governed by two factors; the current carrying capacity of the electrodes

and the furnace resistance. The temperature of the electrodes must be kept below a certain level in order to avoid oxidation of the upper part of the electrodes, and also — most probably — to limit the current from the electrodes to the mixture in the upper part of the bed. The temperature of a conductor depends upon two factors, namely the heat generated and the heat liberated.

The heat generated, say  $Q_1 = K_1 W$  where  $K_1$  is a constant and  $W$  the electrical load. The electrical load  $W = RI^2$ , where  $R$  is the resistance of the conductor and  $I$  the current. The resistance is directly proportional to the length of the conductor and inversely proportional to its cross-sectional area, or

$$R = S L/A$$

where  $S$  = specific resistance

$$L = \text{length}$$

and  $A$  = cross sectional area, which for a round conductor =  $\pi D^2/4$

where  $D$  is the diameter of the conductor.

The heat lost from the skin of the same round conductor, say  $Q_2 = K_2 \pi D L$  where  $K_2$  is the emission factor. During equilibrium  $Q_1 = Q_2$  or  $K_2 \pi D L = K_1 I^2 S L / \pi D^2 / 4$

$$\therefore I^2 = K_3 D^3$$

where  $K_3 = K_2 \pi^2 / 4 K_1 S$  and  $I = K_4 \sqrt{D^3}$

$$\text{where } K_4 = \sqrt{K_3}$$

Theoretically the current carrying capacity of an electrode is proportional to the square root of diameter cubed.

Electrodes of the Söderberg type built today are of diameters from 60 to 70 inches and the current capacity of the order of 100 to 120 kA.

Assuming that a furnace is equipped with electrodes of sufficient diameter to carry 100 kA the following calculations are designed to show the effects of furnace resistance ( $R$ ) and furnace reactance ( $X$ ) on the various important parameters of a submerged arc furnace installation.

### Furnace Resistance ( $R$ )

The resistance of a submerged arc furnace falls normally within the range 0.5 to 1.5 milliohms. Table 1 shows the profound effects on smelting load, power factor and electrical efficiency produced by changes within this range of furnace resistance. A reasonable figure for the resistance ( $RL$ ) in the transformers, leads and those parts of the electrodes not submerged in the charge is about 0.1 milliohm.

**TABLE 1**

Furnace resistance (milliohms)	0.5	1.0	1.5
Smelting load ( $3RI^2$ ) MW	15	30	45
Power Factor $\frac{R+RL}{(R+RL)^2X^2}$	0.51	0.74	0.85
Efficiency Factor $\frac{R}{R+RL}$	0.83	0.91	0.94

*Furnace Reactance (X)*

The reactance of a submerged arc furnace depends upon various factors: (a) frequency of the supply (b) interlacing and length of the bus bars (c) electrode length below the contact clamps (d) distance between the electrodes. The last three factors are closely associated with furnace design. The reactance of the latest open type ferro-silicon furnace is about 1 milliohm.

Again, assuming a furnace with a current of 100 kA and a resistance of 1 milliohm. Table 2 shows the effect on furnace parameters produced by changes in the reactance of the furnace.

**TABLE 2**

Furnace reactance (X) milliohm	0.5	1.0	1.5
Smelting load ( $3RI^2$ ) MW	30	30	30
Furnace load $3(R+R_c)I^2$ MW	33	33	33
Reactive load ( $3XI^2$ ) MVA <sub>r</sub>	15	30	45
Power factor (MW/MVA)	0.91	0.74	0.59
Transformer required $\sqrt{(MW)^2 + (MVA_r)^2} = MVA$	36.2	44.6	56.0

As will be obvious, the main effects of reduced reactance are in raising the power factor and decreasing the size of transformer required.

This brief treatment emphasises the critical importance of low reactance and low resistance in the furnace leads and the special importance of a high furnace resistance.

A considerable degree of control over resistance can be secured by adjusting the position of the electrodes within the charge. By pulling the electrodes further from the bottom of the charge, the resistance within the furnace can obviously be increased. This procedure is, however, open to many serious disadvantages (a) it becomes more difficult to maintain the necessary superheat in the metal (b) the top zone of the charge becomes much hotter than is desirable with resulting severe wear on the roof in the case of a closed furnace and electrode equipment in open furnaces (c) the preheating effect of the gases rising from the hottest area around the tips of the electrodes is largely lost.

Finally, trying to operate with the electrodes submerged to only a shallow depth in the charge may have most deleterious effects in those smelting processes in which a gaseous intermediate is formed — as in the

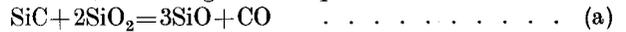
production of ferro-silicon — or when one of the products has a high vapour pressure, e.g. manganese when smelting ferro-manganese.

The implications of this problem of resistance within the furnace and the maintenance of the best metallurgical operating conditions may be illustrated in the production of ferro-silicon and ferro-manganese.

**PRODUCTION OF FERRO-ALLOYS**

*Ferro silicon*

In the production of ferro-silicon the main reaction believed to take place in the hottest part of the furnace underneath the electrodes is that between quartz and silicon-carbide, forming carbon-monoxide and silicon-monoxide, according to the equation:



Silicon-monoxide and carbon-monoxide are vapours at existing temperatures and move upwards through the mixture. After releasing heat to the mixture, the carbon-monoxide escapes to the surface without doing any work but possibly reducing some rust on the steel scrap.

Silicon-monoxide vapour, on its way upwards, reacts with carbon in the coke or char and forms silicon-carbide according to the equation:



It is this SiC which again reacts with quartz underneath the electrodes.

Surplus silicon-monoxide which cannot find carbon to react with, condenses in the mixture, becomes unstable and splits into silicon and silicon-dioxide according to the equation:



Silicon-dioxide again reacts with silicon-carbide underneath the electrodes, but the silicon reacts with the iron in the steel scrap and the result is ferro-silicon.

The process is basically a distillation process, and the advantage of giving the silicon-monoxide time to condense is understandable. Thus a deep electrode penetration is preferable as is a permeable charge to allow condensation of the SiO. Shallow penetration and channelling in the charge result in the silicon-monoxide escaping with the carbon-monoxide and both being oxidised by the oxygen in the air. The result is heavy amounts of finely dispersed 'white smoke' of SiO<sub>2</sub>.

In order to combine a high furnace resistance with a deep electrode penetration and a loose mixture in 35-40-45 MVA ferro-silicon furnaces in Europe, English gas coke is used to a great extent, apparently reacting well with silicon-monoxide, so that a high percentage of SiC comes down into the main reaction zones, increasing the resistance of the furnace charge. Besides this, coal and wood chips are also used to quite an extent, in order to increase the electrical resistance in the solid charge and to improve the permeability of the mixture, so aiding silicon-monoxide condensation. Even so, in operation the tops of these big furnaces can get very hot, and the construction firms go to great lengths to prevent overheating of the equipment. We therefore find the smoke-hoods completely water-cooled, the transformer located in the gallery, the flexibles placed above the smoke-hood in order to be as cool as possible. The

current is brought in by water-cooled copper pipes through the hood to the contact pads and around the electrode assembly there is fitted a water-cooled stainless steel jacket. In order to decrease the reactance, the smoke-hood is brought down as far as technically feasible above the furnace bed and austenitic stainless steel is used in the hood, where the current carrying copper pipes go through it.

These big furnaces are very sensitive to variations in the charge mixture, and the correct proportioning of raw materials is absolutely essential. Drying of the coke is introduced at some plants. Segregation of the mixture can upset the operation to a great extent, therefore small furnace bunkers and small batches are used.

Even though many of these big ferro-silicon furnaces are operating successfully overseas, it appears that the power consumption is still a bit on the high side — higher than would be anticipated. What the result will be here with local raw materials, is still to be seen.

There are good reasons for being quite optimistic about the situation. As compared with furnaces overseas of the same size as ours, our power consumption is favourable. This is most probably a result of favourable raw materials. The felsparite of the Witbank area, even though it cracks slightly during heating, does not disintegrate into fines, so reducing the permeability of the mixture for free gas penetration. After charcoal and lumpy petroleum coke, coal char is believed to be one of the most suitable reductants for Fe Si smelting. This is most probably due to a nearly complete reaction with silicon-monoxide according to the equation:

$\text{SiO} + 2\text{C} = \text{SiC} + \text{CO}$  . . . . . (d)  
 which means that  $\frac{1}{2}$  of the carbon-monoxide is formed higher up in the mixture and only  $\frac{1}{2}$  underneath the electrodes. Besides this, a higher resistance underneath the electrodes can be expected when SiC enters in place of carbon.

As South Africa is an industrialised country, small sized steel scrap in the form of turnings is available. Small sized steel scrap results in the alloying reaction between iron and the silicon produced according to reaction (c) taking place rather high up in the furnace, and the heat liberated from this exothermic reaction results in a lower electric power consumption than if the reaction takes place lower down in the furnace bottom of the hearth due to the limited reactivity where heavy scrap is used.

#### High Carbon Ferro-Manganese

This alloy, usually containing 70 to 80 per cent of manganese, is produced in both blast furnaces and electric furnaces, as is done in this country.

The electric furnace has the advantage of operating with a charge containing much less carbon than obtains in the blast furnace, so that in addition to the high carbon ferro-manganese, a slag with a very high manganese oxide and a low iron oxide content can also be produced. This slag is used as a starting material for silico-manganese production.

The trend today is to go for increasingly larger electric furnaces for the same reasons as for ferro-silicon production, namely reduced depreciation and labour costs.

The operating problems arising are more or less the same as for big ferro-silicon furnaces, namely furnace resistance and smoke losses. Therefore, again it is the question of combining deep electrode penetration with a comparatively high resistance.

Let us first look at South Africa, where high carbon ferro-manganese is produced at a number of places including Amcor's works at Kookfontein. We have the oldest furnaces in South Africa, and they are not as good as furnaces built recently. The reactances are of the order of 1.15 milliohms and in order to maintain a power factor of at least 0.8 without batteries of condensers, we need a furnace resistance of:

$$\frac{R}{\sqrt{R^2 + X^2}} = 0.8 \quad \text{so } R = 1.53 \text{ m } \Omega$$

We have been able to achieve this resistance in the charge by introducing reductants of higher resistivities, thereby maintaining a deep electrode penetration and a reasonable power consumption. If metallurgical coke were used as a reductant, the required resistance could only be reached by operating with very short penetration of electrodes. This would result in a very hot top operation, causing damage to the furnace refractory roofs and heavy smoke losses.

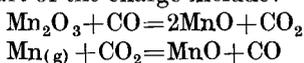
In contrast with silicon-monoxide which is unstable below a certain temperature and also has a low boiling point, manganese monoxide is stable up to very high temperatures and has a melting point of 1 785°C.

The reduction of manganese monoxide with carbon is:

- (a)  $\text{MnO} + \text{C} = \text{Mn} + \text{CO}$
- (b)  $3\text{Mn} + \text{C} = \text{Mn}_3\text{C}$

As the boiling point of manganese, however, is only 2 095°C it is understandable that some of the manganese formed in the hottest part of the furnace, namely underneath the electrodes, evaporates and may condense again in the cooler charge in the upper part of the furnace. If any manganese vapour reaches the top of the charge it will re-oxidise, forming the so-called manganese 'smoke'.

Additional reactions which may occur in the upper part of the charge include:



The second reaction involves the production of MnO resulting in the formation of finely dispersed particles of MnO escaping from the burden forming manganese 'smoke'.

To minimise the formation of manganese 'smoke' it would appear that a fairly substantial depth of relatively cool charge is required between the surface and the tips of the electrodes. This should permit the reduction of the higher oxides of manganese to MnO to be affected by the CO gas before reaching the higher temperature zone just underneath the tips of the electrodes. In addition, the manganese vapour can be condensed and carried down into the high temperature zone. If the higher oxides of manganese are reduced in the zone above that in which manganese vapour condenses, then the reaction:



cannot easily occur. Obviously the occurrence of this reaction is highly undesirable as it involves using manganese as a reducing agent.

In Japan I saw an example of how these problems of furnace resistance and smoke losses were attacked, both from a metallurgical point of view and from constructional and operational innovations. The results from the Mizushima No 2 furnace on high carbon ferro-manganese production were presented in *Tableaux Illustrant l'Inter-vention* in Paris in June, 1969, by Dr J. Nasu.

The data in this paper shows that the operation is characterised by the use of a relatively large size coke (25-60 mm) and a low slag to metal ratio of 0.585. These two factors should result in a furnace charge of very low resistance with accompanying shallow penetration of electrodes and hot charge tops. From the figures given in Table 2 of Dr Nasu's paper the resistance of the furnace charge can be calculated and comes to 1.147 milliohms which would be associated with deep penetration of the electrodes. This apparent anomaly can be resolved and the explanation appears to lie in the continuous operation of the furnace with a bath of slag about 1 m deep.

This constant slag bath is obtained by having the tapholes for slag and metal at different levels, the metal tapholes being plugged against the metal stream, a practice common in matte smelting operations. The furnace operation is extraordinarily smooth, and very little smoke arises from the bed. A possible explanation for this may be a good transfer of heat from the electrodes out through the slag bath so minimizing local overheating underneath the electrodes.

A furnace resistance of 1.147 milliohms cannot be considered very high, but this Japanese furnace has a reactance of 0.89 milliohms on a 60 cycle supply. The power factor may therefore be calculated as:

$$\frac{R}{\sqrt{R^2+X^2}} = \frac{1.147}{\sqrt{1.147^2+0.89^2}} = 0.79$$

For this furnace the resistance is sufficient for the capacity of the electrodes.

An interesting little calculation is to combine the resistance of the furnace typical of our present operations, with the reactance of the Mizushima furnace on a 50 cycle supply, in the case of electrodes able to carry 120 kA.

$$\text{Furnace load: } 3 \times 1.5 \times 10^{-3} \times 120\,000^2 = 64\,800\,000 \text{ Watt} = 64.8 \text{ MW}$$

$$\text{Reactive load: } 3 \times 0.7416 \times 10^{-3} \times 120\,000^2 = 32\,037\,000 \text{ VAR} = 32.037 \text{ MVAR}$$

$$\text{Power factor: } \frac{64.8}{\sqrt{64.8^2+32.037^2}} = 0.9$$

$$\text{Transformer capacity: } \frac{64.8}{0.9} = 72 \text{ MVA}$$

To my knowledge no high carbon ferro-manganese furnaces in the world are working on such a high load, but the possibility for furnaces of this size appears to be within reach. As shown earlier, a low reactance is of critical importance in order to keep the size of the transformers within reasonable limits.

Coming back to the blast furnace operation, we have the situation that mainly old small furnaces, which are no longer economically suitable for pig iron production, have been converted to high carbon ferro-manganese production. Metallurgically the processes vary considerably because iron oxide, to a very great extent, is reduced by carbon monoxide to iron in the shaft, but manganese monoxide is first reduced in the bosh by carbon. The coke rate for high carbon ferro-manganese therefore naturally becomes much higher, and alloy production drops to about 50 per cent of that obtained when operating on pig iron. Interesting experiments, especially in Russia, have shown that production can be brought back to normal by increasing the oxygen content in the blast to about 30 per cent. The coke consumption is also somewhat reduced as compared with the use of the air blast.

The possibility of the use of an oxygenated blast raises interesting questions regarding the design and operating of blast furnaces for ferro-manganese production. The use of the oxygenated blast inevitably results in lower temperatures in the upper part of the stack so that little benefit results from the height of the stack in the conventional blast furnace. In addition the conventional blast furnace requires large quantities of expensive and relatively scarce metallurgical coke. Consideration should be given therefore to the possibility of blast furnaces with reduced stack height (the so-called low shaft blast furnace). This further opens up the feasibility of using a cheaper type of fuel than metallurgical coke.

A further important factor is that much of the manganese ore in this country is of the braunitic calcitic type, which is not highly suited for the production of high carbon ferro-manganese and enriched slag using the normal submerged arc furnace process. These ores however constitute a self-fluxing burden for blast furnace operation. For these reasons it is possible that some type of low-shaft blast furnace using an oxygen-enriched blast may prove the most economical equipment for high carbon ferro-manganese production in this country.

#### *Ferro-Chrome*

Coming to high carbon ferro-chrome production, it is quite amazing at the present time not to find the same tendency for much larger furnaces as is the case for ferro-silicon and high carbon ferro-manganese production.

In the normal high carbon ferro-chrome process the furnace resistance is rather high, and due to the high boiling point of Cr of 2500°C the smoke losses are small.

An explanation for the continued use of the small furnaces could be the chrome ore situation.

Due to exhaustion of mines, boycott and other political reasons, the supply of hard, lumpy metallurgical grade chrome ore is limited. We therefore find more of the friable, so-called chemical grade being employed for metallurgical purposes.

The first step was then naturally to try to use the friable ores in existing high carbon ferro-chrome furnaces, and many plants appear still to be at this stage. It is amazing

how much fines can be tolerated in submerged arc furnaces of limited size without heavy blows and eruptions taking place, but the situation is naturally far from satisfactory, and it is unlikely that giant size furnaces can tolerate such an excessive proportion of fines. It is therefore understandable that the question of agglomeration must be solved before large size furnaces can be introduced. The possible agglomeration processes which could be introduced are briquetting, sintering and pelletizing. Of the three, the tendency appears to be towards pelletizing. Agglomeration adds extra cost to production and the profit margin of ferro-chrome has not been exceptionally high. A different situation exists if other benefits, for instance upgrading and pre-reduction, can be included in the agglomeration process. In Japan, there is already one plant operating on pre-reduced pellets, containing a very high percentage of pre-reduced iron and chrome. A considerable saving in electric power

is obtained which makes the process very attractive in countries with expensive power. It may be mentioned that the furnace resistance with a pelletized charge is very high and 2.5 milliohms appears to be well within reach, which could make electric furnaces of the 100 MW range possible.

What is for us of utmost importance, is that we can expect an increased interest in our friable Transvaal chrome ores. It would, however, not be entirely satisfactory just to export the ores as such, if a higher profit could be secured by exporting pre-reduced pellets and/or ferro-chrome instead.

I am very pleased to know that an intensive study of the matter is taking place at the National Institute for Metallurgy and other research organisations and I am convinced that in the very near future we shall be able to make use of the results in the industry.

