

Factors Affecting Carbon Consumption in the Production of High Carbon Ferromanganese

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ABSTRACT

The stoichiometric amount of carbon required to reduce the lowest oxides of Mn, Fe to their metallic components to produce HCFeMn alloy is calculated to be about 275 kgC/t HCFeMn. All HCFeMn smelting operations consume more than this with consumption varying from about 305 to 380 kgC/t of smelted alloy, or 10 to 30% above the stoichiometric amount, and even higher in some cases. As carbon consumption increases it will also result in an increase in power consumption. All of the mechanisms that cause this increase and variation in carbon consumption occur in the solid state, that is solid-gas reactions in the mix burden.

Many of the factors that can affect these reactions, such as depth of mix in a furnace, bed porosity, ore type and size, etc., have been investigated. A process model (multi-stage steady state reactor) of the HCFeMn furnace has been built and lab-scale experiments have been done on the ore, coke and fluxes, to better understand these mechanisms. Operating data from two Eramet furnaces in Marietta OH, USA have also been examined in detail. The results of these studies have helped in better understanding the reasons behind the higher fixed carbon consumption. This improvement in process knowledge has led to better control of the furnace operation.

1. INTRODUCTION

In the smelting of HCFeMn in an electric arc furnace, adding the correct amount of coke (fixed carbon) is required in order to obtain a cost efficient and stable operation. Adding too much coke causes build-up of coke in the furnace and a poor operation with higher power and coke consumption. Adding

too little coke will result in insufficient reduction of the slag and an unstable operation. Both result in higher costs and lower production rates. However, determining and adding the correct amount of coke can be a complex and at times a very difficult process.

The stoichiometric or minimum amount of carbon required to reduce the lowest oxides of the metals produced, e.g. Mn, Fe is calculated to be about 275 kg C/t HCFeMn (Table 1). All HCFeMn smelting operations consume more carbon than this with consumption varying from about 305 to 380 kg/t of smelted alloy. The mechanisms that cause this increase and variation in carbon consumption are a direct or indirect result of the solid-gas reactions in the mix burden. The extents of the solid-gas reactions are affected by factors like depth of mix burden, porosity of mix burden, ore size and reactivity, etc. An overview of the reactions that cause an increase in carbon consumption in the furnace and the factors that control the extent of these reactions will be given in this paper.

2. FERROMANGANESE PRODUCTION AT ERAMET, MARIETTA, OH, USA

High Carbon Ferromanganese (HCFeMn) is produced at Eramet Marietta Inc. in submerged arc furnaces. The main raw materials in the HCFeMn process are manganese ores, and carbon in the form of coke. Highly oxidized manganese ores like Comilog (MnO_2) are normally used as the main source of Mn units. Iron units in the form of millscale are used as required to produce an alloy with around 13% Fe as the ores are deficient in iron. Coke serves as the reducing agent. The solid-gas reactions occur in the mix burden with the primary reaction being the reduction of the higher

oxides of manganese to MnO by the rising CO gas. In the lower part of the furnace, the ore is melted in a coke bed which is found to be under the electrode tip¹. The liquid oxides get directly reduced by carbon in the coke bed to form alloy.

Table 1: Calculation of the minimum theoretical fixed carbon requirement in a HCFeMn furnace

| Element | Wt % | Reaction | Kg C/ton of alloy |
|--|------|--|-------------------|
| Mn | 79.0 | $\text{MnO} + \text{C} = \underline{\text{Mn}} + \text{CO}$ | 172.6 |
| Fe | 13.7 | $[\text{Fe}^{++}] + [\text{O}^-] + \text{C} = \underline{\text{Fe}} + \text{CO}$ | 29.4 |
| Si | 0.3 | $\text{SiO}_2 + 2\text{C} = \underline{\text{Si}} + 2\text{CO}$ | 2.6 |
| C | 7.0 | $\text{C} = \underline{\text{C}}$ | 70.0 |
| Total minimum theoretical carbon required = | | | 274.6 |
| In addition Mn(g) from 2% loss as fume = | | | 3.2 |

Table 2 : Typical alloy and slag composition of the ferromanganese furnaces at Eramet Marietta Inc.

| | Mn | Fe | Si | C | |
|-------|------|------|------------------|--------------------------------|------------------|
| Alloy | 79.0 | 13.0 | 0.3 | 7.0 | |
| | MnO | CaO | SiO ₂ | Al ₂ O ₃ | K ₂ O |
| Slag | 45 | 4.0 | 22 | 20 | 2.8 |

3. MINIMUM CARBON CONSUMPTION

The minimum carbon consumption calculation is made by assuming that under ideal conditions, all of the oxygen above MnO will react with CO to form CO₂ and generate energy. It is also assumed that the energy contained in these gases will remove the CO₂ in the carbonates, vaporize the chemically bound water and free moisture, and preheat the mix. The amounts of other trace elements in the alloy (~0.7%) will have minimal impact on this determination and are added as iron for this calculation.

For this calculation it is assumed that carbon (rather

than CO gas) is required for the reduction of FeO. This is because the iron in manganese ores is present as complex compounds in minerals like Jacobsite (Fe₂MnO₄), Rhodonite (Mn,Fe,Ca)SiO₃, and Bixbyite (Mn,Fe)₂O₃². The iron contents in manganese ores are also quite low, ranging mainly in the range of 2 to 10% and averaging about 5% in the ore blends used. So the ferrous ions in the manganese ores are present at low activity and are difficult to reduce to metallic iron by CO gas. It is assumed in this paper that this does not happen.

4. SOLID-GAS REACTIONS

As stated previously, all the operations consume more carbon than the theoretical minimum of 275 kgC/t of smelted alloy. This additional carbon consumption is occurring in the burden or the coke bed. It is not always predictable and can vary depending on furnace conditions. Understanding more about what these reactions are and what produces favourable or unfavourable conditions for them to occur will, however, results in improved control of these operations. A list is given below of the reactions that are expected to occur between the mix burden and the ascending gas produced in the smelting zone. These reactions are listed as occurring in zones over certain estimated temperature ranges. It should be understood that many of the reactions which can occur in the lower temperature zones may not occur until a higher temperature zone is reached depending on several variables which are discussed later. It will then be shown that the amount of carbon that will be consumed in producing HCFeMn will be dependent upon the extent of these reactions and can vary over a wide range.

Zone 1 ~ Temperature range 100 to 400 degrees C

- $\text{F.H}_2\text{O} \rightarrow \text{H}_2\text{O} (\text{g})$ (F.H₂O = surface or physical moisture)
- $2\text{MnO}_2 + \text{CO} \rightarrow \text{Mn}_2\text{O}_3 + \text{CO}_2$
- $\text{MgCO}_3 \rightarrow \text{MgO} + \text{CO}_2$
- $\text{MnCO}_3 \rightarrow \text{MnO} + \text{CO}_2$

Zone 2 ~ Temperature range 300 to 700 degrees C

- $\text{MgCO}_3 \rightarrow \text{MgO} + \text{CO}_2$
- $3\text{Mn}_2\text{O}_3 + \text{CO} \rightarrow 2\text{Mn}_3\text{O}_4 + \text{CO}_2$
- $\text{Mn}_3\text{O}_4 + \text{CO} \rightarrow 3\text{MnO} + \text{CO}_2$

- $2[\text{Fe}^{+++}] + 3[\text{O}^-] + \text{CO} \rightarrow 2[\text{Fe}^{++}] + 2[\text{O}^-] + \text{CO}_2$
- Chem. Bound $\text{H}_2\text{O} \rightarrow \text{H}_2\text{O}$

Zone 3 ~ Temperature range 600 to 1200 degrees C

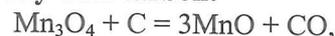
- $2\text{Mn}_2\text{O}_3 + \text{CO} \rightarrow 3\text{Mn}_3\text{O}_4 + \text{CO}_2$
- $\text{Mn}_3\text{O}_4 + \text{CO} \rightarrow 3\text{MnO} + \text{CO}_2$
- $2[\text{Fe}^{+++}] + 3[\text{O}^-] + \text{CO} \rightarrow 2[\text{Fe}^{++}] + 2[\text{O}^-] + \text{CO}_2$
- $\text{CaCO}_3 \rightarrow \text{CaO} + \text{CO}_2$
- H_2 (volatile) $\rightarrow \text{H}_2$
- $\text{CO}_2 + \text{C} \rightarrow 2\text{CO}$
- $2\text{K}(\text{g}) + \text{CO}_2 \rightarrow \text{K}_2\text{O} + \text{CO}$

Zone 4 ~ The following reactions occur primarily in the coke bed in the liquid state above 1200 °C

- $\text{Mn}_3\text{O}_4, \text{MnO}, \text{FeO}, \text{SiO}_2, \text{CaO}, \text{MgO}, \text{Al}_2\text{O}_3, \text{K}_2\text{O} \rightarrow \text{Mn}_3\text{O}_4$ (slag), MnO (slag), FeO (slag), SiO_2 (slag), CaO (slag), MgO (slag), Al_2O_3 (slag), K_2O (slag) (all go into the slag)
- Mn_3O_4 (slag) + $\text{C} \rightarrow 3\text{MnO} + \text{CO}$
- MnO (slag) + $\text{C} \rightarrow \text{Mn}(\text{g}) + \text{CO}$
- MnO (slag) + $\text{C} \rightarrow \text{Mn} + \text{CO}$
- FeO (slag) + $\text{C} \rightarrow \text{Fe} + \text{CO}$
- SiO_2 (slag) + $2\text{C} \rightarrow \text{Si} + 2\text{CO}$
- $\text{C} \rightarrow \underline{\text{C}}$ for carbon to the metal.
- Chem. Bound $\text{H}_2\text{O} + \text{C} \rightarrow \text{H}_2 + \text{CO}$
- K_2O (slag) + $\text{C} \rightarrow 2\text{K}(\text{g}) + \text{CO}$
- P_2O_5 (slag) + $5\text{C} \rightarrow \text{P}_2(\text{g}) + 5\text{CO}$
- P_2O_5 (slag) + $5\text{C} \rightarrow \text{P} + 5\text{CO}$
- As_2O_5 (slag) + $5\text{C} \rightarrow \text{As}_2(\text{g}) + 5\text{CO}$
- $\text{CaCO}_3 + \text{C} \rightarrow \text{CaO} + 2\text{CO}$

The 5 main reactions that can consume carbon above the calculated minimum are a) the reaction of oxygen above MnO directly with carbon shown in zone 4, b) the reaction of chemically bound water with carbon shown in zone 4, c) the reaction of the CO_2 in calcium carbonates (particularly those carbonates associated with dolomite) with carbon also in zone 4, d) potassium recirculation shown in zone 3 and e) Boudouard reaction shown in zone 3. Each of these reactions will in addition consume a considerable amount of energy. This in turn could impact on how the reactions in the burden will proceed. Knowing how to predict with some degree of reliability how these reactions will proceed is vital to evaluating and predicting furnace performance.

a) Some oxygen above MnO reaches zone 4 and reacts directly with carbon:



$$\Delta H_{298\text{K}} = 28980 \text{ cal/mol Mn}_3\text{O}_4$$

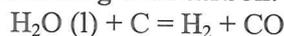
This reaction will consume 0.052 kg C/kg Mn_3O_4 . Say 30% of the Mn_3O_4 reaches the coke bed. It requires about 2 ton of ore to produce a ton of alloy. An ore containing 79% MnO_2 would produce 693 kg Mn_3O_4 per ton of ore. With 30% of the Mn_3O_4 not reacting with CO, the carbon consumption will increase by 21.6 kg C/t alloy.

$\text{Mn}_3\text{O}_4 + \text{CO} = \text{MnO} + \text{CO}_2$ reaction gives out a heat energy of 12230 cal/mol Mn_3O_4

So by 30% of the Mn_3O_4 in the ore not reacting with CO, the energy consumption would be increased by 87 kWh/ton of alloy.

The amount of Mn_3O_4 that reaches the coke bed depends on the reaction kinetics of the ore and the residence time of the ore in the furnace. Lower reduction kinetics (related to ore porosity, size, mineralogy etc.) and a lower residence time (due to a shallow furnace, short electrodes etc.) of the ore will cause more Mn_3O_4 to reach the coke bed.

b) Moisture from the chemically bound water and in some cases free moisture entering zone 4 and reacting with carbon.



$$\Delta H_{298\text{K}} = 41896 \text{ cal/mole H}_2\text{O}$$

This reaction consumes 0.67 kg C /kg of water. Since chemically bound water does not begin releasing until temperatures of over 300 to 400 °C are reached, any burden slumping could make this water reach zone 4. Ores used at Eramet Marietta Inc. contain about 4% chemically bound water. If all this water enters the zone 4, this would equal 80 kg of water/t alloy (using 2 tons of ore per ton of alloy). This reaction is also highly endothermic and would increase the carbon consumption by 53.6 kg of carbon/t alloy.

Energy consumption would be increased by 162 kWh/t alloy.

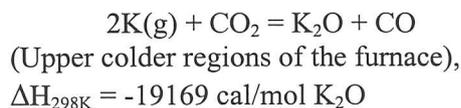
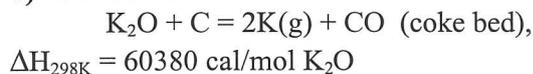
c) The CO_2 from carbonate decomposition entering zone 4 and reacting with carbon:



$$\Delta H_{298\text{K}} = 42018 \text{ cal / mole CO}_2$$

This reaction consumes 0.27 kg C/kg of CO₂. This reaction is also highly endothermic. It is possible to have no carbonates in a mix blend. If a small amount of dolomite is used, say 45 kg per ton ore, that amounts to 40 kg CO₂ per ton of alloy. If all this entered zone 4 it would consume 10.8 kg C/t of alloy. Energy consumption would be increased by 44 kWh/t alloy.

d) Potassium recirculation.



This reaction consumes 0.127 kg C/ kg K₂O

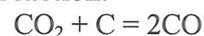
The reduction of K₂O occurs in the coke bed and forms potassium, which is vaporised at the high temperatures present in this area. The potassium vapor rises and reacts with the CO₂ gas in zone 3 and redeposits as solid potassium oxide or potassium carbonate in the upper cooler regions of the furnace. The potassium effectively recycles within the furnace, consuming fixed carbon. The evidence for potassium recirculation is very strong. Firstly all operators have observed extensive potassium-containing banks during digouts and relines. Secondly Tronstad¹² has documented extensive accumulation of potassium (> 100 tons) in the burden during the start-up of a furnace. Thirdly in pilot scale experiments, Tangstad observed very low potassium contents (increasing from 0.1 to 1%) in the slag during successive taps from start-up when the steady-state potassium was expected to be around 4.25 %^{5, 6}. She also observed K₂O buildup in the burden of the pilot-scale furnace.

The potassium recirculation, involving two reaction steps, is equivalent to a single step Boudouard reaction. It is interesting to note that, in their overall effect, Boudouard reaction and potassium recirculation are indistinguishable to the furnace operator. The extent to which each mechanism contributes to fixed carbon consumption is currently unknown. Modelling studies however have shown that potassium recirculation may be a big factor.

For a typical ore blend Li⁸ used data from Turkdogan⁹ to estimate the activity coefficient of K₂O in the slag. A four zone reaction model of the furnace then pointed to a recirculating potassium load of 9.0 times the input potassium in the ore. This would consume 46 kg C/t alloy. The energy consumption would be increased by 183 kWh/t alloy.

It is to be noted that the potassium recirculating load is very sensitive to the activity coefficient of K₂O in the slag. Until experiments are done to measure the activity coefficient of K₂O in a ferromanganese system slag, the calculated carbon consumption amount will be subject to uncertainty.

e) Boudouard reaction.



This reaction consumes 0.27 kg C/kg of CO₂ and is highly endothermic. The CO₂ gas that is produced by the reduction of the higher Mn oxides could theoretically react with carbon according to the Boudouard reaction and lead to additional carbon consumption. Work by Szekely has shown that the kinetics of the Boudouard reaction are only fast at high CO₂ concentrations (CO₂/(CO+CO₂) > 0.3) and at high temperatures (>1000 °C)¹. In the FeMn furnace, this combination of circumstances does not happen. However the kinetics of the Boudouard reaction may increase considerably in the presence of alkalis, though the amount of increase under the conditions in a ferromanganese furnace is not known. Alam and DebRoy¹⁰ found that the presence of 2 wt% Na₂CO₃ in the coke increased the rate of Boudouard reaction by 8 times in a pure CO₂ atmosphere at 850 °C.

Our modelling work⁸ has shown that in the upper part of the furnace, the CO₂ content in the gas is high but the temperatures are low. In the lower part of the furnace, the temperatures are high but the CO₂ content of the gas is low (CO₂/(CO+CO₂) < 0.3). Table 3 (a, b and c) shows the pCO, pCO₂ and temperatures in the various zones for different assumptions regarding the zone reactions. Only when all the oxygen above MnO in the ore is consumed by solid-gas reactions does the ratio CO₂/(CO+CO₂) reach near 0.3 in zone 3. It is also worth noting the decrease in the zone 3 temperature

when Boudouard reaction replaces potassium recirculation.

If all the CO₂ produced by the gaseous reduction of 70% of the Mn₃O₄ in zone 3 is consumed by Boudouard reaction, it will increase carbon consumption by **50.3 kg C/t alloy**.

Energy consumption would be increased by **207 kWh/t alloy**.

Table 3: The variation of pCO, pCO₂ and temperature in the various zones in response to different reaction zone assumptions in the model

(a)

| Standard case with potassium recirculation, no oxygen above MnO reaches coke bed and no Boudouard reaction | | | | |
|--|----------|-----------------------|--|----------|
| | Mol % CO | Mol % CO ₂ | CO ₂ /(CO+CO ₂) | Temp. °C |
| Zone 1 | 7.9 | 43.9 | 0.847 | 426 |
| Zone 2 | 40.5 | 34.3 | 0.458 | 661 |
| Zone 3 | 52.7 | 22.1 | 0.295 | 1012 |
| Zone 4 | 79.5 | 0 | 0 | 1420* |

(b)

| Standard case with 20% of the oxygen above MnO in the ore reaching the coke bed | | | | |
|---|----------|-----------------------|--|----------|
| | Mol % CO | Mol % CO ₂ | CO ₂ /(CO+CO ₂) | Temp. °C |
| Zone 1 | 22.5 | 32.4 | 0.590 | 415 |
| Zone 2 | 57.4 | 19.7 | 0.256 | 638 |
| Zone 3 | 68.2 | 8.9 | 0.115 | 955 |
| Zone 4 | 81.3 | 0 | 0 | 1420* |

(c)

| Potassium recirculation replaced by Boudouard reaction to give same outlet CO ₂ as in standard case | | | | |
|--|----------|-----------------------|--|----------|
| | Mol % CO | Mol % CO ₂ | CO ₂ /(CO+CO ₂) | Temp. °C |
| Zone 1 | 7.9 | 43.9 | 0.847 | 409 |
| Zone 2 | 40.5 | 34.3 | 0.458 | 588 |
| Zone 3 | 52.7 | 22.1 | 0.295 | 774 |
| Zone 4 | 90.5 | 0 | 0 | 1420* |

* - this is an assumed hearth temperature, all other temperatures calculated from heat balance

f) Net Effect of Reaction Extent

It is impossible to calculate the individual amounts of the carbon consumption through the various possibilities listed above by using the furnace operating data. Some of the reactions are also interconnected. For example, it is known that potassium in the raw material leads to potassium recirculation in the furnace and it also acts as a catalyst for the Boudouard reaction. An increase in the potassium content of the raw material could increase the net carbon consumption in the furnace but it will not be known whether this increase was caused by an increase in Boudouard reaction or by an increase in the potassium recirculation. Specific experiments would have to be done to isolate the effect of the two reaction mechanisms.

The total potential increase in carbon consumption and energy consumption is summarized in Table 4 below. For all of the different conditions described this adds up to 133 kg C/t alloy. Note that the Boudouard reaction and potassium recirculation reactions are not additive. This then indicates that a potential total carbon usage of 408 kg C/t alloy is possible compared to actual usage recorded in Eramet of up to 380 kg C/t alloy for our shallowest furnaces. This seems reasonable, and quite obviously indicates that depending on furnace conditions, at least more than one of these reactions are occurring and most likely several of them are to varying degrees.

Table 4: Increase in carbon and energy consumption in the furnace due to inefficient solid-gas reactions

| | Carbon, kg C/t new alloy | Energy, kWh/t alloy |
|--|--------------------------|---------------------|
| Minimum carbon Consumption | 275 | |
| 30% of Mn ₃ O ₄ produced reaches zone 4 | 22 | 87 |
| Bound water at 4% of ore reaches zone 4 | 54 | 162 |
| Carbonates at 2% of ore reaches zone 4 | 11 | 44 |
| Potassium recirculation or Boudouard reaction consuming all CO ₂ produced in zone 3 | 46 | 183 |
| | 50 | 207 |
| Total increase = | 133 | 476 |

Increase in Carbon consumption = 133 kg C/t alloy or increase of 48.4% over the stoichiometric amount
Increase in Energy consumption = 476 kWh/t alloy or increase of 21.6% over the stoichiometric amount (typically 2300 kWh/t alloy for a 30% Mn slag)

5. FACTORS AFFECTING SOLID-GAS REACTIONS

The extent of the solid-gas reactions is dependent upon the following known factors:

- The ability of the oxygen "above MnO" in an ore to react with CO to produce MnO and CO₂.
- The porosity of the mix burden to allow contact of the gas with the ore.
- The size of the ore particles
- The depth of the furnace mix burden – affected by furnace design and the size of the coke bed
- The amount of recirculating alkalis (particularly potassium)
- Reactivity of the coke in the mix burden

- The amount of moisture, hydroxides, carbonates and other energy requirements in the mix

Many of these factors are dependent upon each other. The levels of the oxygen above MnO in an ore blend can vary from nothing (MnO) to highest (MnO₂) and any level in between. For discussion purposes, it can be assumed that all of the oxygen above MnO will react with CO to form CO₂. This reaction will generate as much as 750 kWh/t alloy produced for an ore like Comilog containing 79% MnO₂. The more oxygen above MnO that an ore contains the more energy that can be generated in the mix burden. Highly oxidized ores thus have the potential to reduce the energy required for smelting HCFeMn by transferring this energy into the mix burden and using it to remove carbonates, hydroxides, free moisture and preheat the mix burden. The extent of this reaction and its energy transfer to the mix burden will have a large impact on both carbon and power consumption.

It will be more difficult to react the oxygen above MnO with CO gas in a large dense piece of ore than it will be to react it with a small and/or more porous piece of ore. This is because the smaller piece of ore has more surface area exposed for the CO gas to react with. In a more porous piece of ore, CO gas will more easily penetrate the ore and thus react with the oxygen.

Comilog ore, because of its porosity, contains more free moisture than most other ores, about 8 % compared to 3% for Groote Eylandt ore and <2% for most South African ores. In the case where there is sufficient depth of mix and highly oxidized ores are used, it is found that higher free moisture contents in the mix do not impact negatively on power consumption, because the excess oxygen in the ore generates more than enough energy to evaporate the moisture. The higher moisture levels merely result in lower temperatures for the gas leaving the mix surface.

6. DISCUSSION

For the best operations at Eramet Marietta Inc. carbon consumption has been as low as 305 kgC/t alloy. On the other hand there have also been operations which consumed up to 380 kgC/t. The

higher carbon consumption was also accompanied by higher power consumption and lower production rates. The solid-gas reactions therefore have a profound effect on operating costs, productivity, and operating revenue. Even with sufficient furnace depth, the amount of carbon consumed can vary. For example, the coke bed (made up of residual coke left in the furnace) can increase in size, due to feeding too much coke for a period of time, leading to shorter electrodes and less mix depth. With insufficient mix depth, the solid-gas reactions will occur to a lesser extent thereby requiring even more coke. As the coke bed becomes even larger it can cause a cooler temperature in the reaction zone, giving less efficient slag reduction and therefore indicating a requirement of even more coke. If the mechanism is not well understood more coke is added and a very poor operation is the result, that is high carbon and high power consumption along with high off-gas temperatures that can damage furnace components.

In the case where the furnace design depth is not sufficient to start with, the operator must be satisfied with higher carbon and power consumption. Many times this less than desirable result is not accepted by the operator. If he then attempts to lengthen the electrodes by reducing the size of the coke bed, he will soon find the coke bed becomes too small, resulting in an unstable operation. Because of the many complex factors that can affect the extent of the solid-gas reactions, many HCFeMn furnaces can operate poorly for many years. Problems also occur when personnel are changed or significant changes are made to the raw materials fed to the furnace. It has been the objective of Eramet, over the last several years to study, document and more fully understand the operation of their furnaces. This knowledge can then be transferred to new personnel who can minimize furnace upsets in the future.

Eramet Marietta Inc. has been working with the University of Missouri-Rolla, the University of Trondheim and Eramet's research lab at Trappes, France to study and understand more fully the mechanisms which can affect the fixed carbon consumption in the production of HCFeMn. These studies have led to improvements in the furnace operation of Eramet. The HCFeMn furnaces, in Marietta for example, now use more of the porous,

high oxygen containing Comilog ores compared to the previous usage of the dense Groote ore and the low oxygen containing South African ores. There is better understanding of the coke bed effect and this has enabled the furnace metallurgist to respond correctly to changes in the size of the coke bed. All these changes over the years have led to an improvement in the alloy production, an increase in the furnace load and a reduction in operating costs (Figure 1). It is intended to continue these studies in the future in order to be able to understand, control, and predict these operations even more reliably in the future.

The advantages of using high oxygen ores such as Comilog with no flux added (called high alumina slag practice), along with operating with a deep mix burden, have been previously reported by R. G. Ratzlaff¹¹. In this report Mr Ratzlaff reported average energy consumption for a 6 month campaign using 100% Comilog ore and no flux additions of 2050 kWh/t versus 2250 kWh/t when using ore blends of South African and Comilog ores. This test was made in the very deep furnace number 18 built by Tanabe for Union Carbide's FeMn plant in Beauharnois, Quebec, Canada. This furnace design allowed for a minimum level of mix from the tip of the electrode to the mix surface of about 3 meters. Although there were some problems controlling chemistry at the time, which are highlighted by Ratzlaff¹¹, his conclusion is quoted as follows: "*The high alumina practice using 100% Comilog ore, at this point in time, is found to be superior to all of the other practices in a number of respects, and hence it has become the standard operating practice for this plant. High productivity results from low energy consumption and high Mn recovery in the alloy. Control of silicon is a constant challenge, requiring close monitoring of the coke bed size.*"

7. CONCLUSIONS

The solid-gas reactions in the burden play a major part on the consumption and/or control of carbon in the production of HCFeMn alloy. Inefficiencies in the solid-gas reactions in the furnace could increase carbon consumption to anywhere in the range of 275 to 408 kg C/t and there would be a corresponding increase in energy consumption. The effects of these reactions are amplified when

highly oxidized ores are used. It is then important that the burden is of sufficient depth in order to take advantage of the potential improvement in energy consumption and productivity which can be achieved from the exothermic reduction of the higher manganese oxides. Under the best conditions this energy can be as much as 750 kWh/ton of alloy produced when using highly oxidized and reactive ores such as Comilog.

This energy will also be available to remove chemically bound water and carbonates. In the case where the burden does not have sufficient depth, or when this depth is reduced by allowing the coke bed to become too large, water and/or carbonates can reach the high temperature zone of the furnace (above 1200 °C). This will then cause an increase

in carbon consumption and add to the energy requirements for producing the alloy.

The factors that control the extent of the solid-gas reactions are quite complex and variable. It has been the objective of Eramet to continuously improve their understanding of these reactions through theoretical and laboratory studies in co-operation with other institutions, and through close examination of operating data from their varied HCFeMn operations world-wide. This knowledge is being systematically transferred to new personnel who will build upon it further. This combined effort is resulting in considerably improved HCFeMn operations within Eramet.

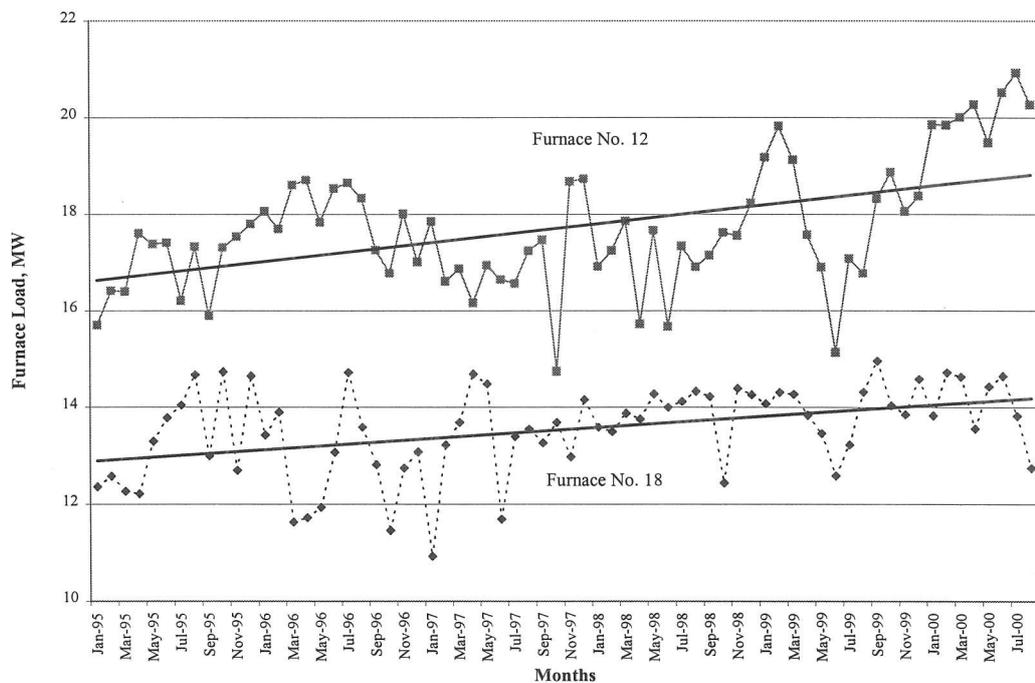


Figure 1: Increase in furnace operating loads for Eramet Marietta Inc. HCFeMn furnaces

8. REFERENCES

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