SILICON SMELTING WITH

SELF-BAKING ELECTRODES

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SUMMARY

Two types of iron-free self-baking electrodes were installed on smelting furnaces which produce calcium carbide and silicon metal. The first comprises a permanent casing and a consumable cylindrical graphite core which could be used on new furnace installations or for replacing electrodes on large existing furnaces. The second type can be installed on existing small furnaces. A description of the electrical conditions characterizes the optimal relation between furnace productivity and electrode consumption.

INTRODUCTION

The high rate of consumption of electrodes associated with the production of silicon metal represents a significant portion of the related manufacturing costs. Usually, semi-graphite or amorphous carbon electrodes supply current to the reaction zones in such furnaces. The production of one ton of silicon metal entails a consumption of over 80 kg of electrode. The benefit derived from reducing electrode consumption is clear, especially in consideration of a unit cost of about $1000/t for semi-graphite electrodes.

An even more attractive possibility is the substitution of self-baking electrodes for the prebaked variety where the potential savings reflect a unit cost of less than 1/2 of that for prebaked electrodes. But, conventional self-baking electrodes require fins and casings which contribute iron (up to 0.5%), and possibly other elements, to the product. Even this small percentage is unacceptable for the use of silicon in the manufacture of silicones and computer chips, imposing strict controls over the smelting process. A previous attempt to address this issue resulted in a self-baking electrode that incorporates a metallic "spine" located at the axis of the column.[1] Electrodes of this design are weak, resulting in considerable breakage, because limiting the amount of metal, results in a reduction in total tensile strength.

A different, simpler, design eliminates the addition of metal from the fins. It is a completely iron-free self-baking electrode, having a cylindrical core comprising a column of smaller graphite electrodes. Testing of the iron-free self-baking electrodes was begun in the early seventies and is continuing in two furnaces at the Carbometal, S.A.I.C. plant in Carrodilla, Argentina. A description of the equipment and the related operating features will be given in later sections of this presentation. Before that, some background will be provided to explain the electrical conduction characteristics of a silicon furnace and their bearing on electrode consumption.

CONDUCTION IN SILICON FURNACES

As is well known, the smelting of silicon involves the production of silicon monoxide, SiO. In the reaction zone cavity below each electrode, the ratio of SiO/CO is about 2. Each cavity has a shape like that of a beehive with the production of silicon taking place on the interior surface of the chamber. The reaction rate decreases in intensity as the distance from the electrode increases.

Arcing might, or might not, accompany the transfer of energy to the charge, but joule heating (I^2R) always occurs. The arcing mode can be detected with the help of an oscilloscope. Normally, with no arc present, an elliptical trace forms with the application of phase-to-neutral current and voltage signals to the X and Y axes. When there is arcing the pattern becomes distorted. According to Keyser[2], the conductive mode produces the best results, since the specific values for consumption of electrode and energy are lower when that mode of operation prevails.

Each type of charge exhibits a limited range of specific conductivity during smelting. That range translates into a unique operational parameter, S/d,* which has the same dimensional characteristics as conductivity. In a silicon charge, joule conduction dominates when S/d becomes less than about 250 Siemens/m. The S/d value varies with each addition or shift of the charge. Consequently, it is affected greatly by stoking.

ELECTRODE SLIPPING RATE

There is almost a direct correspondence between the specific electrode consumption, and the S/d parameter. This fact became evident upon rearranging some of the excellent data presented by Westly[3] for Figure 1.

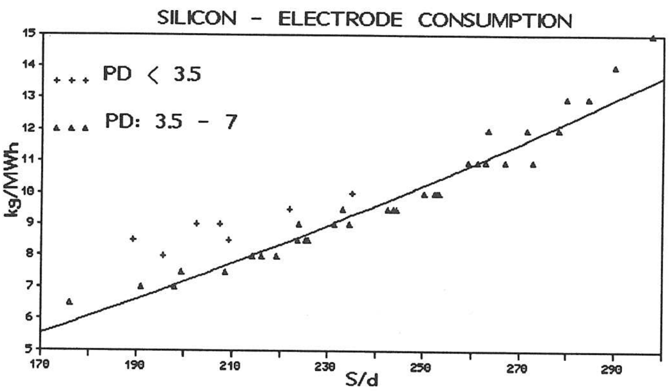

Figure 1. The plot shows that the unit electrode consumption, kg/MWh, is almost a linear function of the conductivity index, S/d. PD is the electrode power density in MW/m^2.

*Conductance, S, is the reciprocal of resistance. The electrode diameter is d.

The data applies to furnaces having electrodes 889 to 1400 mm in diameter and incorporate electrode power densities much lower than 6-7 MW/m^2 - the apparent optimal range. Excluding very low values of PD produced the exponential curve included with the data. With respect to electrode consumption, a silicon furnace should be operated at the lowest possible value of charge conductance. This implies avoiding the arc mode completely since the conductance of an arc is indeterminate.

Experience indicates that the level of electrode consumption is greater during the production of silicon than during the manufacture of ferrosilicons. This fact causes concern in the application of self-baking electrodes to silicon smelting. Ordinarily, baking becomes a problem when the rate of linear consumption exceeds a certain limit. When the casings are consumable, the difficulties arise when unbaked paste reaches the lower edges of the contact plates. This occurs at a slipping rate of about 50 mm/h . The electrode casing becomes oxidized almost immediately as it slips below the lower edges of the plates, owing to the high temperatures encountered there. Because of insufficient baking, the electrode is weak and is susceptible to breakage.

This problem can be avoided by operating with a value of S/d less than 250 Siemens/m. It can be avoided entirely if a sufficient thickness of electrode paste can be baked adjacent to the inner surface of the casing before it reaches the contact pads. The heat necessary for baking can be obtained by exposing the casing just above the contact plates to heated gases. These can be directed into the annular passage between the casing and the surrounding mantle. Alternatively, the mantle can end at a level above the plates enabling the furnace gases to bake the electrode paste within the casing. These considerations have been taken into account in the development of the iron-free self-baking electrode, resulting in the cessation of electrode breakage.

IRON-FREE SELF-BAKING ELECTRODES

The iron-free self-baking electrode employs a permanent casing, and axially connected smaller graphite cylinders which form a solid core upon which conventional electrode paste can be baked. As the paste bakes it bonds itself to the graphite core. The bond strength after baking is greater than that of the baked paste. If the core occupies 10% of the cross section, it can support approximately four times as much load as can the fins in a normal self-baking electrode. Because of this, the design of the electrode column guarantees complete support of the electrode mass by the core. Also, a smaller than usual slipping and holding mechanism can be employed, owing to the higher pressures which can be applied to the solid graphite cylinder.

Since there is no casing consumption, means must be provided for baking the paste above the contact shoes. Exposing the casing to the furnace gases in the region above the contact pads handles this requirement. The pads themselves have smaller areas than those of the conventional contact plates used on self baking electrodes. Large contact areas promote heat loss while providing for current transfer only along very narrow band at the bottom edge of each pad.

RETROFIT

The preceding dealt with a design of iron-free self-baking electrode intended for new installations. Another type is being tested, successfully, to provide a simple design for existing furnaces. It has no graphite core and employs conventional holding and slipping means for electrodes with diameters up to about 1m . The electrode casing is slipped with the paste , but this poses no problem since it oxidizes rapidly once it is exposed to the intense heat of the furnace gases below the contact plates. Consequently, no casing metal reaches the charge. As in the prototype electrode, paste-baking must occur above the contact plates.

REFERENCES

(1)M.D. Cavigli, U.S. Patent 3,619,465. NOVEMBER 1971

(2)N.H. Keyser, "A New Look into the Smelting Crater of a Silicon Reduction Furnace" Electric Furnace Conference Proceedings. A.I.M.E 1984, Vol.42

(3) J. Westly, "Electrode Consumption in Production of 75% FeSi and Si-met." Electric Furnace Conference Proceedings. Vol 42, pp 157-160