PAPER • **OPEN ACCESS**

Improving the management process of the carbothermic reduction of metallurgical silicon

Improving the management process of the carbothermic reduction of metallurgical silicon

S A Martynov and V Yu Bazhin

Saint-Petersburg Mining University, 2, 21st Line, St Petersburg 199106, Russia

E-mail: direktor062@mail.ru

Abstract. The paper considers the current state of the metallurgical industry including the issues of automating the production of metallurgical silicon in ore-smelting furnaces. The main problem areas are revealed in the production cycle of obtaining metallurgical silicon, such as the lack of operational information on the moisture and ash content of the reducing agent, a static error in the testimony of furnace ammeters at different levels of the furnace transformer, the absence of a system of bypass electrodes under load. As a recommendation, the introduction of a three-tier control system, the modernization of the weighing and dosing system for charge materials, and the system for the automatic transfer of electrodes without shutting down the furnace are proposed.

1. Introduction

The current state of metallurgical silicon production and its technical level is determined by the degree and level of its automation. The lack of necessary control and measurements of technological parameters reduces the possibility of increasing the efficiency of ore-smelting furnaces (OSF). During the operation of OSF there are a number of processes that are currently performed manually. Some of them have to be automated.

Silicon is used as a deoxidizing agent, an alloying element, a modifier of metal properties. It is a raw material for the production of semi-crystalline silicon in the chemical industry, it is used in the production of silicon-organic materials, silanes. It is also used for the production of solar cells. Therefore metallurgical silicon is an important strategic material, and its special properties make it indispensable in various industries.

2. Production status of metallurgical silicon

In the world in 2017, the production of silicon was about 2.17 million tons, with approximately 58% of silicon produced in China. The volume of production in Russia is only about 3% of the world output, which is about 60 thousand tons.

The main areas of technical silicon application are as follows (%): metallurgy - 45; chemical industry - 35; production of photovoltaic cells - 12; semiconductor manufacturing - 3; others –5.

The main raw material for the production of metallurgical silicon is quartzite. This is a metamorphic rock, quartz grains in which are bonded with silica, it consists for about 98% of almost one mineral - quartz, and it also contains compounds of aluminium, iron, etc. [1].

IOP Conf. Series: Materials Science and Engineering **537** (2019) 022028 doi:10.1088/1757-899X/537/2/022028

For the charge quartzite is mainly used, which is characterized by better hiding and a lower content of impurities. The chemical composition of quartzite is as follows (%): 99 - SiO_2; 0.051 - Al_2O_3; 0.032- Fe_2O_3; 0.023 - CaO.

Quartzite of different grades is stored separately, and it is prohibited to mix them according to the technical regulations. The choice of the quartzite grade is carried out by technological personnel and it is rational to introduce technical input control at this stage using a non-destructive control system for separating charge streams from the warehouse to loading into the furnace.

The main reducing agent of quartzite is charcoal, which is produced in two-channel, circulating type furnaces by the pyrogenic processing of wood [2]. Charcoal has a high porosity – 72-80%, which determines its high sorption capacity. The moisture of the coal during unloading from the retort is not controlled. It should be about 2-4% for OSF according to the technological instruction, but since coal is stored in bulk in closed warehouses, the humidity rises to 7-10% [3]. This is one of the main problems of the enterprise, as there is no operational information about the moisture content of charcoal and it causes an imbalance of carbon in the OSF. As a result it leads to a constant alternation of "heavy" and "light" charge ("heavy" means a high content of quartzite, “light " means a high content of reducing agent). Uncontrolled input of charcoal with high moisture often leads to furnace carbon deposit. The high humidity of the reducing agent leads to a sharp decrease in the resistance of the charge materials and, as a result, to a violation of the technological process, up to the furnace shutdown.

After an overhaul of the furnace, it is required to put it into operation effectively, and for this, in order to avoid oxidation of the side coal lining, it is necessary to apply lime mortar to the surface before drying. According to the instructions, before loading the petroleum coke, the mine is freed from ash after drying. A layer of coarsely crushed petroleum coke (class from +15 to +70 mm) is poured on the hearth with a height of 500 mm with tamping it to the walls of the furnace. Under the electrodes, the oil coke is levelled, and one coal block is placed under them for the lining of the moulds. All these operations are performed manually and are not technically controlled.

Before switching on the furnace, the current-carrying parts are carefully visually inspected in order to avoid metal objects between the busbar plates. The lifting mechanisms of the electrodes are checked manually. After ensuring that all the mechanisms are in good condition, voltage is applied to the furnace electrodes, while the electrodes must be 100 mm higher from the coke pad. This distance is not measured and set based on experience. After that, the furnace is turned on, and the arc is ignited with a current of 8-10 kA. The arc power is raised according to the heating schedule according to the technological instruction (figure 1).

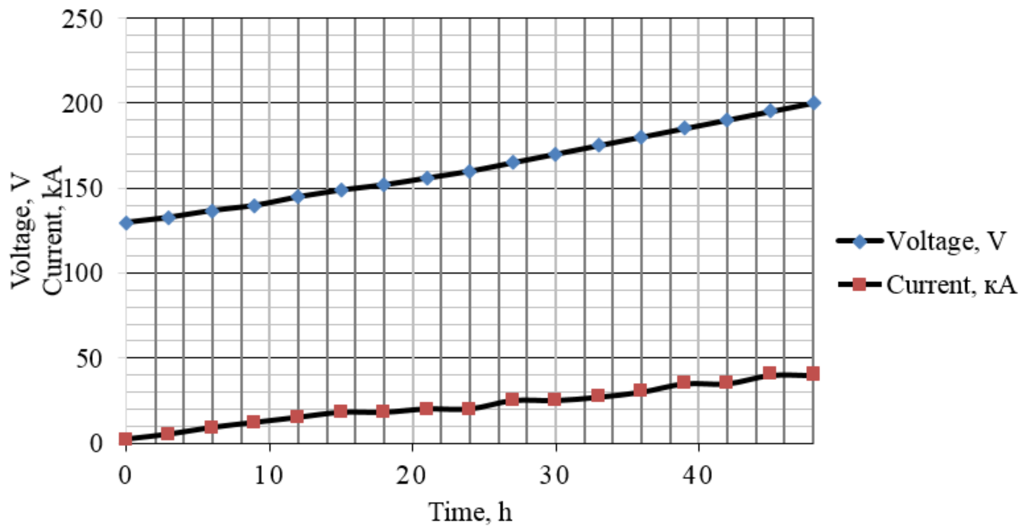

Figure 1. Schedule of OSF warming up after the overhaul.

IOP Conf. Series: Materials Science and Engineering **537** (2019) 022028 doi:10.1088/1757-899X/537/2/022028

As a rule, the heating time of the furnace is 48 hours. At this stage, one should strictly monitor the presence of a layer of petroleum coke under the electrodes in order to avoid burning the bottom of the electric arc. The system of non-destructive testing with an integrated matrix can provide control of this process, and help to avoid negative effects on the furnace hearth.

One of the main tasks in OSF management is to determine the state of the end of the electrode and its true length, its position in the furnace space, and also to control the distribution of thermal fields. At the enterprise, the state of the electrode is determined only during scheduled preventive maintenance (SPM), during which the furnace is stopped, the electrode is raised and the state of the electrode end and its length are visually assessed. Existing control systems can calculate a reduction in the length of the electrode in terms of power, but they do not give a reliable result, since this process is uneven during the operation of the furnace.

The plant uses the process control of smelting technical silicon is carried out by changing the amount of reducing agent in the mixture. Changes in the composition of the mixture with excess and lack of reducing agent, taking into account incorrect dosing of charcoal due to the lack of operational information about its moisture and ash leads to a deterioration in the quality of process control and a decrease in the yield of useful products. The solution to such a problem may be an adaptive control system that will take into account the current carbon balance in the OSF.

An analysis of current load control and management systems revealed the shortcomings of the existing electrode bypass system. This operation is usually carried out in manual mode with the furnace disconnected from the power supply. The operation of the bypass of the electrodes is accompanied by a forced external water-cooling, since due to the high temperatures it is impossible for the operating personnel to approach the contact plate. This operation is repeated for each electrode separately, which leads to an increase in downtime. For example, after a minimum downtime of about 7 minutes, it takes about 30 minutes to return the process to the previous mode [4]. In this case, the position of the electrodes becomes asymmetric, which leads to the asymmetry of the current load, and according to the existing control method, without taking into account the location of the electrode, different weights of charge for different electrodes are applied.

It is also worth noting that the console ammeters accurately display the value of the low side current only for the third stage, because the devices are calibrated in the values of the low side current corresponding to the third stage, and the current value of the other stages is shown with a static error. It was recorded that with a true current value at the first stage of 39.4 kA, when the ammeter reads 42 kA at the fifth stage, the current strength value will be 45 kA. Working on the first stage, the furnace does not receive a load of 5-10%. On the other hand, work with low voltage is associated with overcurrent, which does not meet the standards of operation of the secondary busbar and has a negative impact on the state of all its elements, which can lead to an emergency stop of the OSF. This indicator is regulating for the impact of the automated process control system on the movement of the electrodes, the bypass of the electrodes, the switching of the transformer stage when regulating the active and reactive power of the furnace.

During the work of the furnace, the operator maintains the electrode in the up position. It was found that in the furnace at this position of the electrode, the charge converges better and, as a result, silicon is produced more intensively. In order to pour the accumulated metal into the moulds, and remove the slag, the electrodes are lowered, thereby heating the lower part of the furnace space. With this approach, management becomes uneven, which affects the quality of silicon and the state of the furnace. While maintaining the electrode in the upper position, the contact surface with the charge decreases, which leads to an increase in resistance and a decrease in the current value. The operator, following the instructions, tries to comply with the electric mode and switches the transformer stage with a higher voltage. With this mode of operation, the installation begins to increase heat generation in the shortest network, and not in the furnace, which leads to an increase in the wear of busbars and electrode holders.

During the refining stage, silicon is blown into the ladle not by technical oxygen, but by air, which reduces the efficiency of the silicon purification process from aluminium and calcium compounds. This is another drawback of the existing technology [5].

The conducted audit revealed the need to create and implement an automatic control system. It is impossible to manage complex devices and OSF operated at the enterprise without modern instrumentation used for process automation. The management of such complex processes will become automatic, the operator's functions will be reduced only to monitoring the process, and rare interventions will be needed only in emergency situations [6].

3. Recommendations

As a recommendation, it is possible to suggest the implementation of a three-tier production management system in the form of a SCADA system. The first level is the level of control by executing mechanisms, polling of field sensors, control of charge materials (ash, mass, moisture content). The second level is the processing of data received from the lower level. On the basis of the algorithm, the calculation of the magnitude of the control action on the actuators and the coordination of the ampere load, as well as the transfer of data on the technological process (current strength, electrode position and geometry, arc length, process temperature) to the enterprise information network. The third level is the enterprise management system and telecommunications. Also at the top level of the automated process control system (APCS), the issue of operational planning and management, feasibility planning and logistics is being addressed.

It will increase the yield of silicon by 5-10% and reduce specific electricity consumption by 3-5% while reducing the consumption of raw materials by 1-2%. The activities allow to systematically improve the working conditions of working personnel [7].

4. Conclusions

A technical and technological audit of silicon production revealed a number of drawbacks and imperfections in the control system, such as:

- lack of operational information on the ash and moisture content of reducing agents;
- lack of automatic electrode bypass system;
- use in the process of refining silicon compressed air, and not technical oxygen;
- lack of modern process control system.

Multi-level automation in the form of SCADA-systems will provide an opportunity to obtain high labour productivity, since there will be practically no dependence between the productivity of the furnaces and the intensity of human labour during the smelting of crystalline silicon [8]. Automated production complexes in the production of silicon will increase social responsibility and labour efficiency, since this is one of the most harmful metallurgical industries.

References

[1] Perepelitsyn V A, Yukseev I V, Maksunov K A and Lubnina A A 2008 Geochemical features of quartzites of the Karaul Mountain deposit (south quarry) *Refractories and Industrial Ceramics* **49(2)** 103-7
[2] Ille J and Vilja P 2013 A synergy code in co-pyrolysis *Oil Shale* **30(4)** 471-90
[3] Do Rosário da Silva e Silva M, dos Santos Ribeiro E A, Barbosa J P *et al* 2018 Quality attributes of commercial charcoals produced in Amapá, a Brazilian state located in the Amazonia *Environment, Development and Sustainability* 1-14
[4] Vorobyev V P, Sivtsov A V and Kozhevnikov G N 1999 Actual problems of obtaining silicon and silicon-containing alloys *Non-ferrous metals* **5** 70-2
[5] Nemchinova N V, Kletz V E and Chernyakhovsky L V 2001 Carbothermal method for producing high purity silicon *Non-ferrous metals* **1** 84-7
[6] Suslov A P A new generation of monitoring and control methods based on electrophysical and electrochemical phenomena in the bath of the ore-thermal furnace *Notes of the Mining Institute* **202** 203
[7] Pedro A A *et al* 2016 *Automated control of operating parameters on the basis of electrophysical phenomena in the bath of the ore-smelting furnace* (Lambert Academic Publishing) 175-80

IOP Conf. Series: Materials Science and Engineering **537** (2019) 022028 doi:10.1088/1757-899X/537/2/022028

[8] Zhukovsky Yu L and Sizyakova E V 2016 The introduction of energy saving and energy efficiency at the enterprises of the metallurgical complex *Notes of the Mining Institute* **202** 155-60