Developments of DC Submerged Arc Furnace Technology for Ferroalloys in China

Zheng Tianhe*, Yang Zhizhong*, Jiang Boqun*, Xie Shucai*, Wu Wenbin*, Liu Zhongwei*, Yao Qun** and Zong Pigong**

*Central Iron & Steel Research Institute(CISRI), Beijing 100081, China
**Xuanhua Sifangtai Ferroalloys Plant, Hebei 075100, China

ABSTRCT

The paper reports on developments of DC submerged arc furnace technology for ferroalloys by CISRI (Central Iron & Steel Research Institute) in China. The results prove the advantages of the process: 6-8 percent energy savings, 40-50 percent electrode savings and other economic benefits. The report describes furnace features, designs and operations.

1. INTRODUCTION

ASEA and others have developed DC furnace technology for ferroalloy production since 1980[1][2][3]. For example, a 40 MVA DC plasma furnace for production of high-carbon FeCr has been built in South Africa which operates with open arc and open bath and 100 percent fine raw materials charged into the furnace through the hollow electrode. Another type is DC submerged arc furnace that is the same as conventional AC furnaces and the process is with submerged arc and the electrode and bath covered with lumpy materials charged through openings in the roof. In China, the second one is mainly developed. This paper discusses the development and industrial application of the DC submerged arc furnace in China.

2. BACKGROUND

Early in 1986, CISRI involved the application of DC furnace technology in the area of ferroalloys. The project for DC submerged arc furnace was supported by Ministry of Metallurgical Industry and related government organizations. A 2.0 MVA single-electrode DC furnace was built in 1989 by CISRI and its cooperator Sifangtai Ferroalloy Plant.[5][6][7] Production trails were done on production of FeSi, FeMnSi, and SiCa at the beginning and then turned into the regular operation for FeMnSi.
The operation results were satisfied. In 1994 another 6.3 MVA single-electrode DC submerged arc furnace for production of FeMnSi was in operation in the same plant. The advantage of the furnace was revealed and the technology was transferred to other ferroalloy producers lately. In 1996, CISRI started the study on three-electrode DC submerged arc furnace and a pilot plant was built.
The development of larger DC submerged arc furnace was due to the growing demands in China. The project of a 16.5 MVA three-electrode DC submerged arc furnace will be proposed soon and a new level of the technology is expected.
Tab. 1 lists DC furnaces developed by CISRI and its co-operators in last ten years. As one of main developer and provider of the DC submerged arc furnace, Fig. 1 shows the work done by CISRI which is also well outlined the development of this technology in China.

Tab. 1 DC submerged arc furnace installations

Plant name & location	Capacity MVA	Products	Upper electrode	Bottom entrance electrode	Date of commission
Sifangtai, Xuanhua, Hebei	2.0	FeMnSi	Single	Graphite	Mar, 1989
Sifangtai, Xuanhua, Hebei	6.3	FeMnSi	Single	Steel, water-cooled	Jul, 1994
Wanfong, Jiaozuo, Henan	2.0	SiAlFe	Single	Graphite	Nov, 1995
Wanfong, Jiaozuo, Henan	2.0	SiAlFe	Single	Graphite	Apr, 1995
Jinli, Dandong, Liaoning	6.3	FeMnSi	Single	Steel, water-cooled	Oct, 1996
Hongyuan, Huangzhong, Qinhai	5.0	FeSi	Three	Steel, water-cooled	Aug, 1996
Huadian, Huangyuan, Qinhai	6.3	FeSi	Single	Steel, water-cooled	Oct, 1996
Baogang, , Baotou, Neimenggu	2.0	SiCa	Single	Graphite	Mar, 1997
Xinyu, Gonghe, Qinhai	5.5	FeSi	Three	Steel, water-cooled	Nov, 1997

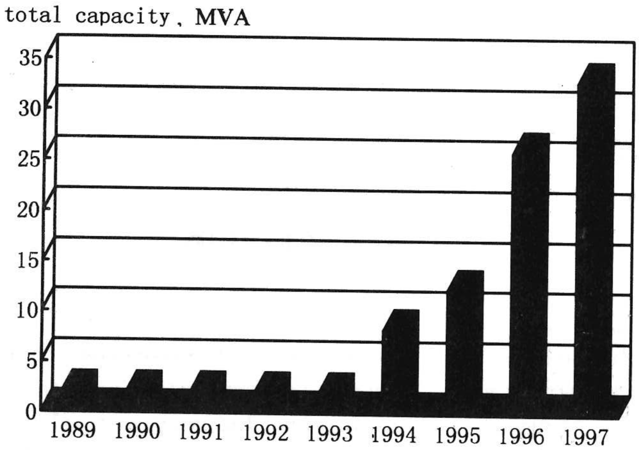


Fig.1 Developments of DC submerged arc furnace in China by CISRI

3. Review of furnace design

Single-electrode DC submerged arc furnace, as shown in Fig. 2 was arranged symmetrically. DC power supply is designed with diode rectifier. Two bottom electrodes were connected to the positive bus tubes and a self-baked electrode connected to the negative bus tubes. Different from AC furnace, carbon lining connected to the bottom electrodes is not only acting as a crucible to hold melts, but also as another pole of DC power.

The bottom electrodes that provide an approach for high current contribute the base to set up a stable process and the main design criteria are:

- high current passing through reliably, no local overheating
- long expectancy life, equal to or longer than the life of carbon lining
- less energy loss
- less current deflection of the bottom electrodes
- being able to restrain arc deviation of the top electrode

Two kinds of the bottom electrode connections were developed. The one adopted the graphite bar as the entrance electrodes which was for small size furnaces. Another was made of metal-materials such as steel bar cooled by water as the entrance parts that fit in middle and large size furnaces. Of these two kinds of connected electrodes, the latter one was not to be wear away which needn't to be replaced. The furnace life depended largely on the carbon lining life.

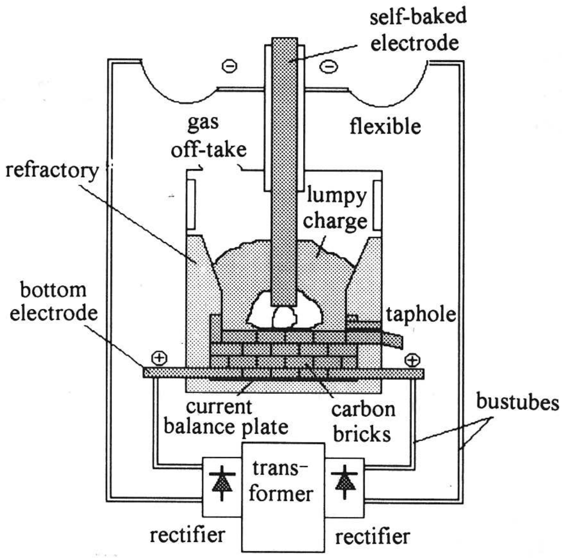


Fig.2 a single electrode DC submerged arc furnace arranged

Tab. 2 lists the several of the bottom electrodes by CISRI and Fig. 3 illustrates the main characteristics of them.

Same as AC furnace, the performance of DC furnace is extremely determined by the meticulous selections of electrical and size extents. Basic concepts for the design of AC furnace, such as electrode current density, reaction area power density, electrode inserted depth, charge resistance, etc., is still valid for the design of DC furnace. It is because that both AC and DC furnaces operate with submerged arc and the metallurgical processes are similar. Thus, the existing well-designed AC furnaces would give available references to the DC furnace design. With the aid of compųter, mathematics modeling can be used to attain important information for the design.

The advantages of single-electrode DC furnace, on the contrary to three-electrode furnace, is uniform heat distribution in the furnace; moreover, electrode holder, smoke hood and other mechanical equipment are easy to be arranged. However, CISRI has still made the effort to develop three-electrode DC submerged arc furnace recently and several reasons are as follows:

- There are many 5-12.5 MVA three-phase AC submerged arc furnaces in China now. If they were converted to DC furnaces, almost all the original three-electrode mechanical system and plant building could be utilized.

Tab. 2 Arrangement and characteristics of bottom electrodes

Type of entrance electrodes	Arrangements and improvements	Current capacity	Bottom voltage	Life expectancy	Manufactured date
Graphite A	Introduced symmetrically on sidewall	20-25kA	2.7 V	1-2 years	1989
Graphite B	Larger section, seal to furnace shell	35-40 kA	2.0 V	5 years	1991
Steel A	Water-cooled, current balance plate adopted	60-80 kA	1.4 V	>5 years	1993
Steel B	Current distributed to control deviation arc	60-80 kA	1.1 V	>5 years	1997

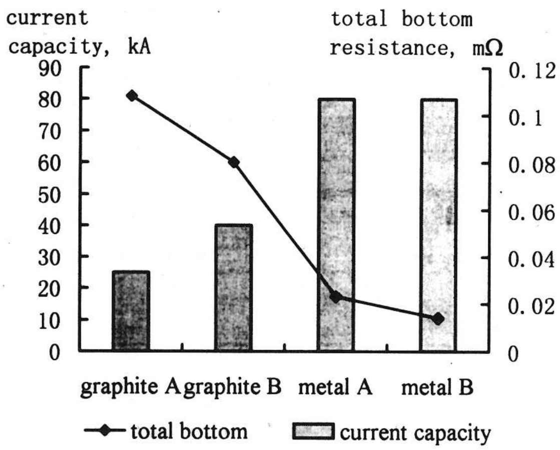


Fig.3 Characteristics and improvements of bottom electrodes

It is a practicable scheme for many ferroalloy producers who want to take use of the DC furnace technology with less investment and time.

- The capacity of single-electrode DC furnace may be restrained because of limited diameter of self-baked electrode. If a single-electrode DC furnace reaches up to 20 MVA or more, the electrode diameter would be close to that of the existing large AC furnace. An alternative is to take advantage of three-electrode DC furnace instead.

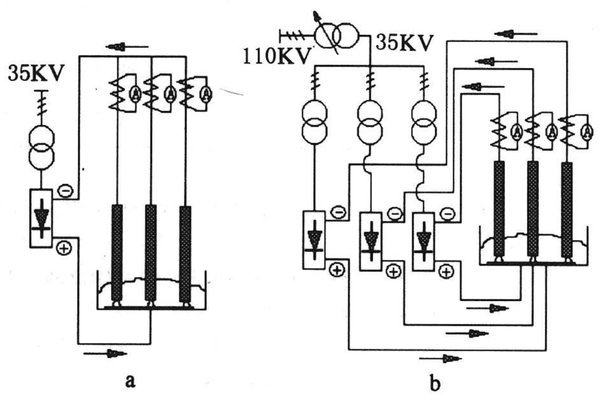
- The problems of making and transporting problems of the large furnace transformer and the rectifier.

The facts mentioned above promote the studying of three-electrode DC furnace. For the three-electrode DC mode, two ways of the power supply could be adopted. The one way is with single set of DC power supply for three electrodes, as shown in Fig. 4a and another provides three sets for three electrodes individually, see Fig. 4b. The former fits to the small furnace, the latter to the middle and large one. The power balance control for three electrodes is by adjusting the current of each electrode.

4. Results and Discussions

During the production of FeMnSi alloy at Sifangtai

Ferroalloy Plant, a 2.0 MVA DC furnace consumed 7 percent less energy than a 3.2 MVA AC furnace that energy consumption was about 4900 kWh/t. Tab. 3 lists the performance indexes of a 6.3 MVA DC furnace at the above plant compared to those of a 9.0 MVA AC furnace in another plant. It should be noted that different operation conditions act on results of energy consumption. The AC furnace had more Mn component in charge; and addition of FeSi75 fine 50 kg/t charging into the furnace was equal to 430 kWh/t attached energy according to FeSi75 specific energy 8500 kWh/t. The saving in the DC furnace was about 250-500 kWh/t FeMnSi, which was 5-10 percent less energy consumption than the AC furnace. Power factor was apparently higher, electrode consumption of DC furnace was only half of AC furnace, and Mn recovery was no difference in both cases.



a. 5.0 MVA DC furnace　　b. 16.5 MVA DC furnace

Fig.4 Three-electrode DC submerged arc furnace arrangements

The same example was also a 6.3 MVA single-electrode DC furnace that belongs to Jinli Ferroalloy Co.; its energy consumption reached the level of 3800kWh/t for the production of FeMn60Si14.

The energy saving for Si-system ferroalloys is similar as above. A 2.0 MVA DC submerged arc furnace of Ferroalloy Plant for smelting FeAlSi (Al 37.42%, Si 25.30%) gave energy consumption about 9500 kWh/t compared with 10000 kWh/t of AC furnace in the same plant. A 6.3 MVA DC furnace at Huadian Ferroalloy Plant for smelting FeSi (Si≥75%) consumed energy about 8500-8700 kWh/t and energy consumption of AC furnaces was more than 9000 kWh/t in the same plant.

Tab. 3　6.3 MVA DC furnace performances compared to AC furnace

Performances and Charge conditions	6.3 MVA DC furnace	9.0 MVA AC furnace
Mn component in ore, mass %	31.09	33.72
Mn yield, %	80.96	80.70
Electrode paste consumption, kg/t	26.9	52
Noise intensity, dB	72	85
Power factor, cosφ	0.94	0.83
Furnace availability, %	98.5	96.0
Products, t/month	922	1050
FeMn65Si17 rate, %	91.7	90
Specific energy consumption, kWh/t	4236	4213
Coke consumption, t/t	0.54	0.52
FeSi75 fine addition, kg/t	-	0.50

A 5.5MVA three-electrode DC submerged arc furnaces was built in Hongyuan plant in 1996 and another same size furnace built in Xinyu plant in 1997. Both of them adopted the arrangement in which three electrodes shared a set of DC power supply as shown in Fig. 4a. The process was more placid and easier control than a single-electrode DC furnace. The performance of the furnaces confirmed that the three-electrode DC furnace has also the same metallurgical results as what of the single-electrode DC furnace. The Xinyu plant's three-electrode DC furnace for FeSi75 showed that power factor reached 0.93, and less noise and less electrode consumption. The energy consumption in the first two months was 8900-9000kWh/t, which had not revealed the best performance since low carbon (73-76%) coke used and other equipment conditions limited the more energy saving.

The performance distinctions between AC and DC furnaces result from the different electrical mechanism in the DC furnace from AC furnace:

- Anode effect of DC arc on the bath, more heat absorbed by melt
- Effect of electromagnetic stirring on the melt caused by high direct current going through the bottom, so heat transferred to the larger area of the furnace bottom
- Bottom resistance heat while current going through carbide pile nearby bottom and carbon lining
- Arc occurring from potential between the top electrode and the bottom instead of among the top electrodes, no matter the single-electrode or the three-electrode DC furnace

With all of above effects, the reaction area in DC furnace is closer to the bottom carbon lining and therefore the bottom rising which often occurred in smelting high silicon ferroalloys is limited. Compared with AC furnace, this so call 'hot furnace bottom' is benefit to the metallurgical reaction.

During the production of FeMnSi at Sifangtai Ferroalloy Plant, it was observed that DC furnace status recovery after heat interrupting seemed to be more quickly than AC furnace (Tab. 4).

Tab. 4 Examples for furnace recovery capability comparison between DC and AC furnace

Furnace type	Duration interruption, min	Duration re-heat, min	First heat productivity, t	Specific energy, kWh/t	Alloy component, mass %	
					Mn	Si
6.3 MVA DC furnace	510	340	4.905	5202	66.06	15.54
	247	337	6.262	4511	64.48	18.08
3.2 MVA AC furnace	450	390	2.591	6502	64.32	14.16
	180	360	2.502	6215	64.76	15.56

Productivity of DC furnace is higher than AC furnace due to high power factor and lower energy consumption and 20 percent increasing has been reported[1] but practical value could be less as a result of the lower DC power output than transformer capacity depended on the type of rectifiers. DC submerged arc furnace shows its advantages in many aspects such as operation, technique, economy and environment:

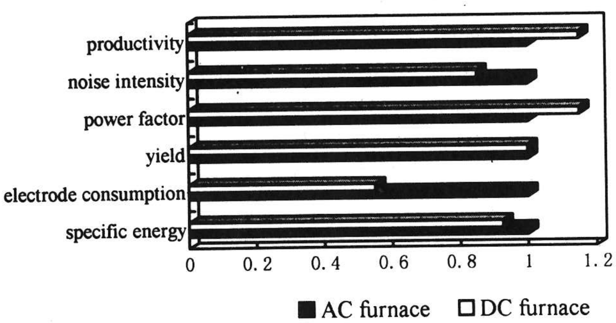


Fig.5 Comparison of main performace indexes between DC and AC submerged arc furnace

- It is easy of tapping, especially in the start-up of the furnace.
- The electrode inserts deeper, easy to control, as well as with higher temperature and better fluid of metal and slag.
- Furnace status recovers more quickly after the interruption.
- The energy consumption is less than AC furnace depending on the condition of power supply, the charge and the operation. 6-8 percent of energy consumption can be normally saved comparing with AC furnace.
- Electrode consumption including electrode shell and paste is 40-50 percent less than what in AC furnace, which is independent from the operation conditions.
- Power factor reaches up to 0.93-0.94 irrelative to the furnace capacity.
- Productivity increases by 10-15 percent dependent on the rectifier type and furnace operation
- Arc burns with less flicker and noise that led to the quiet circumstance for operators.

Almost all of performances are better than that of AC furnace exception of the same yield.

All the efforts have, of course, to be made in both furnace design and operation based on practical situation before the expected target can be reached, but anyhow all of operating DC furnaces are showing the promising results. As well, accumulation of experience and further studies are always necessary.

5. Conclusion and prospect

Practices of the DC submerged arc furnace for ferroalloys production confirmed the advantages of the process including energy saving and other economic benefits. Compared with AC furnace, except for yield is the same, specific energy reduces by 6-8 percent, electrode consumption saves 40-50 percent, noise intensity decreases 7-13 bB, power factor rises up to 0. 93-0. 94, productivity increases by 10-15 percent. These advantages make DC submerged arc furnace manifests well prospects for the industry application in China. DC submerged arc furnace technology is still under development. Large-scale DC furnace and application for different ferroalloys are the important area and CISRI will continue to explore on this area.

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