# TECHCOMMENTARY

# DIRECT CURRENT ELECTRIC ARC FURNACES

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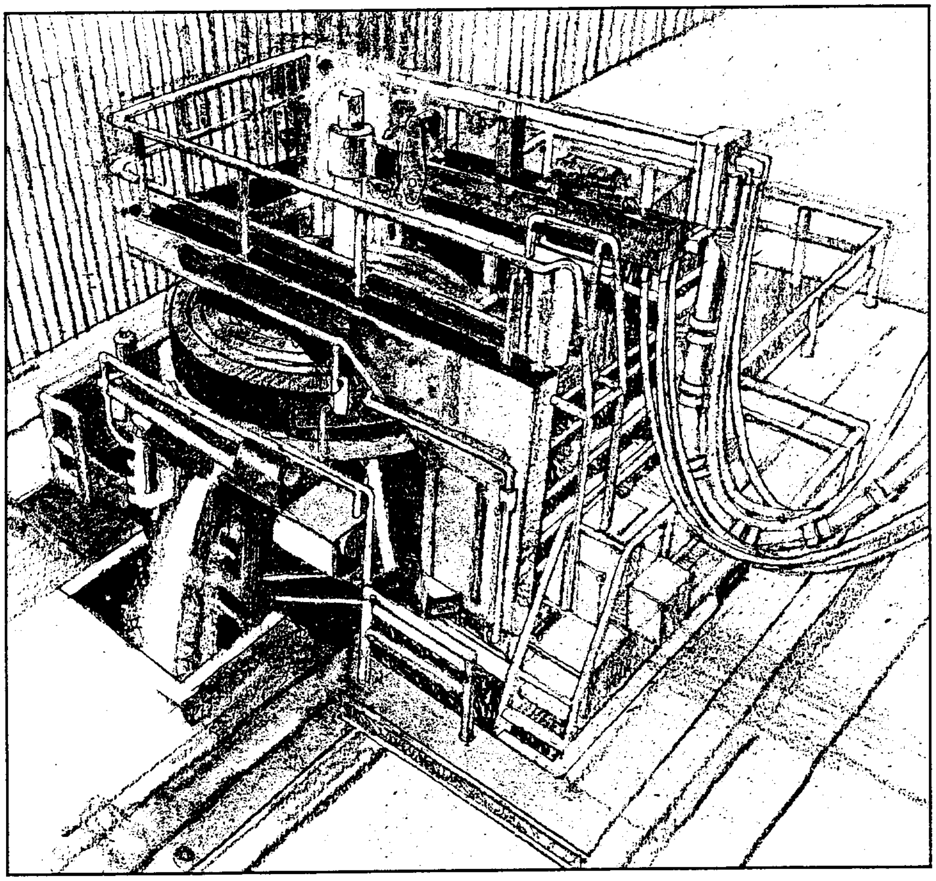
## A GROWING TECHNOLOGY IN ELECTRIC STEELMAKING



**A typical single-electrode, dc electric arc furnace.**

### INTRODUCTION

Electric Arc Furnaces (EAFs) are producing an increasing portion of the steel made in the United States. In 1990 approximately 37% of the 98 million tons of raw steel produced was tapped from EAFs. Ninety-nine percent of this EAF total was supplied by conventional alternating current (ac) EAFs...the remainder came from two dc furnaces.

However, dc furnaces represent a different concept in arc furnace design, which after a decade of trial applications in Europe, is now attracting strong interest in Japan and North America. Tokyo Steel has installed a 130-ton dc furnace at its Kyushu Works. Florida Steel is installing a 60-ton furnace in their Tampa plant. This furnace will replace two 30-ton units, one of which is a furnace that was retrofitted to dc in 1986. Also, Charter Steel in Wisconsin is installing a 60-ton dc furnace. Many more installations are under active consideration as of early 1991.

### WHAT IS A DC FURNACE?

The conventional alternating current arc furnace operates by means of electric current flowing in three-phase operation from one electrode of three to another through the scrap charge (Figure 1). Most dc furnaces are single-electrode units where the current flows down from the carbon electrode, which serves as a cathode, to an anode in the bottom of the furnace (Figure 2). A few dc furnaces are of the three-electrode type where the current flows from each of the top electrodes to a bottom return electrode.

**Steel mill operators are attracted to dc furnaces by a variety of potential advantages.**

Reduced electrode consumption is the major benefit of a dc furnace compared to a conventional three-phase ac furnace. Electrode oxidation loss is lower when only one electrode is utilized instead of three. Steady operation of the electrode in the cathode state is more electrically conductive and cooler. In addition, the more stable arc operation in the dc furnace, as compared to the ac furnace, undoubtedly contributes to reduced electrode consumption. Studies have reported decreases of 50 to 60 percent. Electrical consumption can be 3 to 5% lower than ac operation. Current flows down through the charge from the carbon cathode to the furnace bottom anode, not across the top of the charge as in an ac furnace. Steady operation of the electrode in the cathode state also results in less energy loss in this area.

It is also reported that noise levels of the dc furnace are lower. Lower maintenance costs are claimed and refractory costs are less for sidewalls but more for the furnace bottom. However, considerable improvement has been made in this area. Florida Steel reported bottom life exceeding 1000 heats per campaign on their 30-ton dc furnace and that 2000 heats are expected with their new furnace.

**Utility Advantages**

Reduced voltage fluctuation lessens the problem of flicker thereby greatly reducing or eliminating the need for costly VAR compensation.

Offsetting the advantages, capital costs for a dc installation are higher than for an ac system; however, reduced operating costs can recoup this difference.

**AC vs DC FURNACES**

| AC Advantages | DC Advantages |
|---|---|
| ▪ Lower installation costs | ▪ Reduced electrode consumption |
| ▪ No bottom electrode | ▪ Lower lining wear |
| ▪ Higher power rating for bigger heats | ▪ Bath stirring |
| | ▪ Better temperature distribution |
| | ▪ Less noise |
| | ▪ Less network disturbance |
| | ▪ Less energy consumption |

Despite the many advantages of dc operation, it is only recently that these furnaces have gained a foothold. The development of low-cost semiconductor rectifiers was the needed breakthrough.

## DC ARC FURNACE DESIGN FEATURES

Essentially, the equipment needed for dc melting has the same configuration as that of a conventional ac furnace shown in Figure 1. The exceptions are the addition of the bottom electrode (anode), a dc reactor, and a thyristor rectifier (Figure 2.) all of which add to the cost of a dc furnace.

Conversion of existing furnaces requires having enough space in the transformer room for the thyristor, reactor, and auxiliary equipment. Also, sufficient space must be available under the furnace bottom for the secondary conductor and cooling equipment for the bottom electrode.

Bottom electrode design has varied with many types being used. (See Figure 3.) These include conductive refractories with a copper external shell, and the multi-pin-type, a manifold having conductive rods passing through the hearth. Both of these have been used on medium-sized furnaces with currents less than 40 kA. A third type consists of a large diameter steel plate fitted in the furnace bottom, the steel being water cooled where it emerges from the furnace.

## TYPICAL RESULTS FOR SINGLE-ELECTRODE FURNACES

**Florida Steel—Tampa Plant**

This is a 35-ton, 14 MVA, 11 MW meltdown dc furnace that was converted from ac to dc. Electrode consumption provided one of the greatest advantages, dropping from 10 lbs./billet-ton to 3½ lbs. In addition, the furnace became simpler and safer to operate...operators don't change electrodes as often, and spend less time on top of the furnace. Also, very little sidewall refractory spraying is required. Environmentally, while there is little difference in the volume of dust generated, there are fewer holes in the roof (single electrode vs three) which permits easier capture of

**DATA FOR OPERATING SINGLE-ELECTRODE DC FURNACES**

| | U.S. | | Japan | |
|---|---|---|---|---|
| | Nucor Darlington | Florida Steel Tampa | TOPY Toyohashi | Tokyo Steel Kyushu |
| Start-up | Jan 85 | March 86 | Jan 88 | Sept 89 |
| Shell diameter | 3.8m | 3.8m | 4.57m | 7.0m |
| Rated capacity | 32t | 32t | 30t | 130t |
| Tapping weights | 30-35t | 30-35t | 30-35t | 120-130t |
| Transformer primary voltage | 13.8kV | 13.8kV | 22kV | 22kV |
| Max melting power | 11.5 MW | 11 MW | 15 MW | 2 × 30 MW |
| Max electrode current | 37 kA | 40kA | 42kA | 100-120kA |
| Electrode diameter | 16″ | 18″ | 18″ | 28″ |
| Electrode regulating system | hydraulic | hydraulic | hydraulic | hydraulic |
| Roof | wtr-cooled | wtr-cooled | wtr-cooled | wtr-cooled |
| Sidewall | wtr-cooled | wtr-cooled | wtr-cooled | wtr-cooled |
| Bottom electrode | air-cooled | air-cooled | air-cooled | air-cooled |
| Conversion/New installation | Conversion | Conversion | Conversion | New |

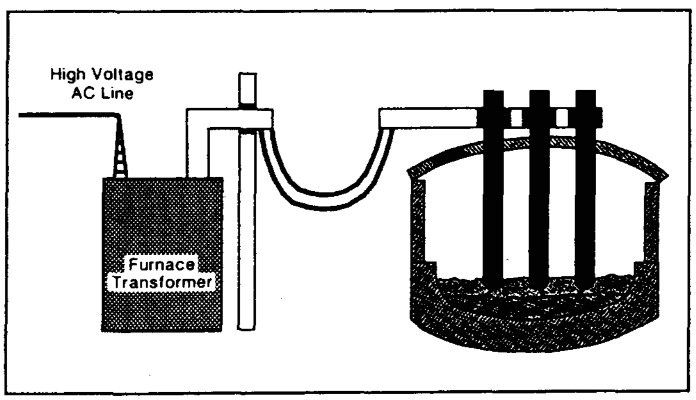



***Figure 1.*** **Conventional ac electric arc furnace.**

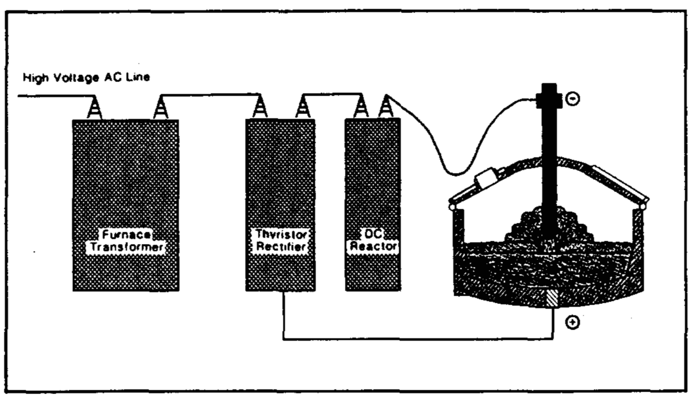



***Figure 2.*** **Layout of dc arc furnace.**

fumes. Based on three year's operation, the decision was made to replace the current furnace and a sister ac furnace of the same size with one 60-ton, 37 MVA dc arc furnace. One feature of the new furnace will be the use of a 12-pulse rectifier compared to the 6-pulse unit on the existing dc furnace. This will eliminate the lower level harmonics (7, 9, 11) which will be beneficial in reducing line disturbance.

**TOPY—Toyohashi Works (Japan)**

This furnace is very close in size and power to the Florida Steel furnace. Following two years of operation, TOPY published results showing cost reductions of 53% in electrode consumption, 5% in power, and 30% in refractory wear. Together these savings add up to $6.00/ton. Electrode consumption has been about 3.2 lbs./ton, and bottom life about 330 heats per campaign. Further improvements are anticipated, with particular attention to increasing the life of the bottom electrode. The expectation is that payback on this conversion to dc will be less than 3 years.

**Tokyo Steel—Kyushu Works (Japan)**

This furnace, with a capacity of 130 tons and 60 MVA, is the largest operating single-electrode dc steelmaking furnace as of 1990. It uses the maximum diameter of commercially available electrodes, 28", permitting a current of about 100 kA. This furnace, which began operation in September 1989, has a rated capacity of 1 million tons/year. Anticipated savings of $15 per ton over ac furnace operation translates to a payback on the added cost of dc in less than two years. Features of the furnace include uniform melting with the central electrode, simple arrangement with the single mount and single secondary conductor, and an air-cooled bottom electrode designed specifically for safety. Advantages claimed for the furnace are:

- 50% reduction in electrode consumption
- 5 to 10% reduction in power consumption
- Greatly reduced refractory consumption
- Uniform melting
- Reduction of flicker level and flicker frequency by half

Production of 23 heats/day and 75,000 MT/mo—rated capacity—were achieved early in 1990. Visitors to the operation confirm that very impressive results are being attained with this furnace.

## NEW DC FURNACES IN THE UNITED STATES

As of early 1991, there are two new dc arc furnaces being installed in the United States. Each features a *single-electrode* furnace. Florida Steel, at their Tampa plant, is replacing two existing 30-ton furnaces with one 17 ft. diameter 60-ton furnace powered by a 37 MVA transformer. Output of the new furnace will be one 35-ton heat about every 45 minutes. Electrode consumption of 3.5 lbs./billet ton is expected, which compares to 10 lbs. on similar ac furnaces. No change is expected in electrical consumption.

Charter Steel, at their Saukville, Wisconsin plant, is installing a 60-ton, 17 ft. diameter shell furnace powered with a 42.3 MVA transformer. Two 35.5 kA, 12-pulse rectifiers will provide the dc current. Electrode diameter will be 24". Initial output of the furnace will be 250,000 NT/year, and start-up is planned for June 1991.

## THREE-ELECTRODE DC ARC FURNACES

While most dc arc furnace installations employ a single, central electrode, an 82-ton capacity, 83 MVA *direct current three-electrode* arc furnace has been operating at SME in Trith St. Leger, France since December 1985. Design of this furnace is based on development work carried out by the French Steel Industry Research Institute (IRSID). Each of the three top electrodes is matched to a bottom electrode in the hearth. Additionally, each electrode has its own transformer-rectifier-reactor assembly. The top electrodes are 22" diameter, and each can draw a maximum of 40 kA. Lower current intensity in the electrodes and the fact that the arc is directed toward the center of the furnace (instead of at the walls in an ac furnace) has resulted in a reduction of electrode consumption and wall wear that approximates that experienced with single electrode dc furnaces. Experience during the first half of 1990 puts electrode consumption at 2.4 lbs./ton. Bottom life has reached about 1500 heats with an expectation of reaching 2000.

**ESTIMATED COMPARATIVE CAPITAL COSTS FOR A 100-TON FURNACE TO PRODUCE 700,000 TONS/YR:**

| | AC $million | DC $million |
|---|---|---|
| Furnace, incl. electrics | 6.3 | 9.5 |
| Burners | 0.5 | not needed |
| Reactive energy compensation | 2.8 (65 MVAR) | 1.0 (30 MVAR) |
| Total Cost | 9.6 | 10.5 |
| Operating Cost (less scrap) | $35/ton | $29/ton |
| Payback on the additional investment | | less than six months |

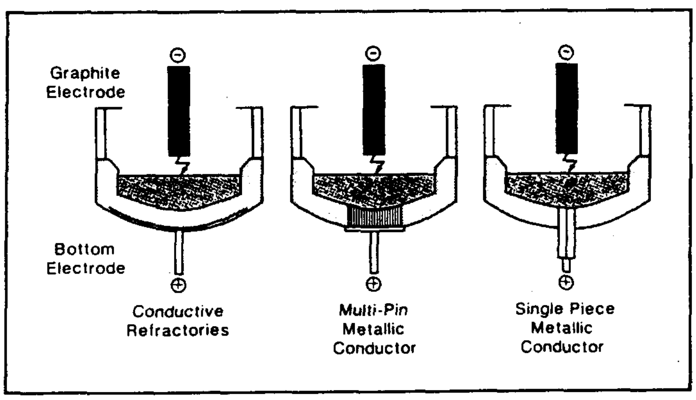



*Figure 3.* **Bottom electrode designs for dc furnaces.**

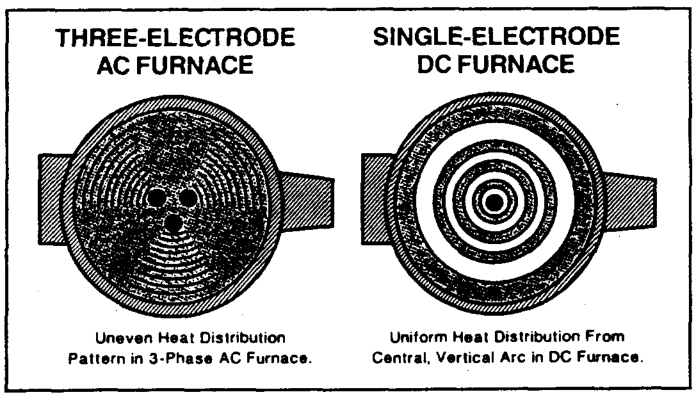



*Figure 4.* **Temperature Distribution—dc furnace operation, particularly with a single electrode produces improved heat distribution. The ac furnace has hot spots on the furnace walls adjacent to the three electrodes typically causing high sidewall refractory wear. The dc furnace produces a uniform heat from a central arc. The resulting temperature profile also promotes convection stirring as an added benefit.**

Kawasaki Steel has installed a furnace with one top and three bottom electrodes which started-up in December 1990. Another furnace has been ordered by Nakayami Steel.

## FUTURE OF DC ARC FURNACES

While it is not clear that dc arc furnaces are the "wave of the future" for steel melting, results obtained in the past five years with furnaces ranging in size from 30 to 130-tons capacity have been very impressive. Interest in these furnaces is high on the part of many domestic steelmakers, and it is reasonable to assume that many more dc furnaces will be installed.

Today's electrode technology limits diameter to a maximum of 28 inches, allowing a dc current of approximately 100 kA, and restricting power to 75 MVA for a single electrode furnace. This in turn limits the size of such a furnace to well under the 200-tons capacity of current large ac furnaces. Perhaps the three-electrode dc furnaces will fill this gap. Another possibility is to develop larger diameter electrodes. At present, the dc furnace offers a potential for substantial savings to the steelmaking industry in ranges up to 75 MVA. Utilities can look forward to fewer electrical disturbances in the power grid.

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