Introduction

The steel industry is comprised of electric arc furnace (EAF) and integrated steel producers. There are significant differences between these steelmaking processes. EAF steelmakers, often referred to as minimills, produce steel by melting scrap, see Figure 1. The integrated steel mills produce steel from iron ore utilizing the blast furnace and basic oxygen furnace processes.

In the integrated process, the blast furnace is provided with energy in the form of coke which is mixed with iron ore pellets/sinter and limestone to constitute a furnace burden. Liquid iron, containing approximately 4% dissolved carbon is tapped from the bottom of the furnace into hot-metal cars and transferred to the basic oxygen furnace (BOF). The metallic charge to the BOF consists of 60 to 70% hot metal from the blast furnace and 30 to 40% steel scrap. The primary function of the BOF is to refine the liquid iron to steel by reducing the carbon to a prescribed level, generally less than 0.5%, as well as removing impurities such as silicon, sulfur, and phosphorus. This is accomplished by injecting oxygen into the bath and the addition of fluxes.

With EAF steelmaking, normally 100% scrap steel is charged to the furnace. In the process, oxygen is also injected and fluxes added to control carbon content and remove impurities. As more high quality steel products are being produced by EAFs, steelmakers are beginning to supplement the scrap charge with direct reduced iron (DRI) and iron carbide. The details of EAF steel production are described in a subsequent CMP TechCommentary titled "Understanding Electric Arc Furnace Operations" (TC-107714).

Because the EAF process is more energy efficient and less capital is required, production of steel by EAFs has increased significantly over the past quarter of a century. In 1996, approximately 39% of the total of 103 million tons of steel shipped was made in EAFs with the balance produced by the blast furnace/basic oxygen process. The total energy required to make one ton of liquid steel in an EAF is about 640 kWh or 6.4 million Btuh on (including electrical energy, burners, and other chemical energy) which is only a fraction of the 19 million Btuh on required using the blast furnace/basic oxygen furnace method.

After melting and refining, the liquid steel is transported to a continuous casting machine where it is cast and solidified. However, a few ingot mold shops still exist. Continuous casting machines produce semifinished sections, i.e., billets, blooms, and slabs. Ingots require an additional rolling operation to produce the semifinished shapes. Final steel products, strip, sheets, bars, rods, plates, tubes, etc., are manufactured from the semifinished sections using a variety of rolling mills and processes.

The Electric Arc Furnace

The first commercial EAF in the United States, a 4-ton unit, was placed in operation in 1906 by the Holcomb Steel Co. at Syracuse, New York. Production increased significantly during World War II, and
again after 1960 with the advent of mini steel mills. Electric furnace steel production increased steadily from 8.4 million tons in 1960 to 42.4 million tons in 1995, or 39% of total steel production. It is expected that EAF steel production will reach 50% within the next 10 years.

The rapid growth in electric furnace steel is due to a number of factors including relatively low investment requirements, improved technology which has reduced production costs, and the generally lower price of steel scrap in comparison with blast furnace hot metal. Capital investment per annual ton of hot-rolled sheets (1996 dollars) is approximately $750 for coke oven/blast furnace, basic oxygen furnace production vs. $213 for electric furnaces.

Approximately 222 electric arc furnaces, ranging in capacity from less than 10 to 400 tons, are operated in the United States by integrated, specialty, and minimill producers. Electric furnaces also are used in some foundry operations with their use doubling since 1957. In general, furnace capacities here are smaller (one to 60 tons) than in basic steel operations. Steel foundries are the principal users of electric arc furnaces. There are approximately 185 foundries with EAFs in the United States.

EAFs consist of a refractory-lined hearth, vertical cylindrical sidewalls, and a removable roof. The graphite electrodes, which pass through holes in the roof, are clamped to arms which move vertically on masts mounted to the furnace assembly. The electrodes and roof can be raised and swung to one side to permit furnace charging. In conventional furnaces, a horizontal tapping spout is built into the hearth structure with a working door located diametrically opposite in the sidewall. The entire furnace unit can be tilted on rockers for tapping liquid steel into a ladle. Electric power is supplied from a 3-phase, multivoltage tap transformer. The electrodes are connected by heavy flexible cables to the transformer which is located as close to the furnace as possible to avoid excessive transmission loss with the heavy currents employed. Most ac furnaces, see Figure 3, have three-electrodes, though some newer furnaces are dc one- or two-electrodes, see Figure 2. Many modern electric arc furnaces also are equipped with oxy-fuel burners.

**Figure 3. An ac Electric Arc Furnace with an Oxygen Lance and Eccentric Bottom Tapping.**
Continuous Casting  
Rolling & Other Mill Processing

**CYCLE**

Basic Oxygen Steelmaking

Sheet  
Plate  
Rod  
Bar  
Shapes

and lances for injecting oxygen, lime, and carbon.

Energy input consists of approximately 60% electrical and 40% chemical which is derived from oxy-fuel combustion, oxidation of carbon, and other chemical reactions. Approximately 53% of the total energy is retained in the liquid steel; heat loss in the waste gases is 20%, cooling losses from the walls and roof 17%, with 10% lost in the slag.

**Operations and Costs**

At the start of a heat cycle, with the electrodes and roof raised and swung to one side, a charge of steel scrap is dropped into the furnace from a clamshell bucket. The roof is replaced, electrodes lowered, and an arc struck. Arc length is optimized to meet the changing conditions during the melting process by selecting the appropriate voltage tap. Two, and sometimes three buckets of scrap, are used in making a single heat of steel. After melting and refining are completed, the heat is tapped into a ladle for casting.

A typical modern melt shop, containing one 19-ft. dia., 120-ton furnace with a 70-MVA transformer, would have an annual melting capacity of approximately 600,000 tons. Average heat times would be close to 1 hour. Power consumption for an efficient operation should be in the range of 360 to 400 kWh/ton. Thus, for a consumption of 400 kWh/ton, the monthly electrical consumption would be approximately 20 million kWh.

Total usage of electric power for the 42.4 million tons produced in the United States in 1995 was approximately 17 billion kwh.

The cost of producing steel in electric furnaces varies considerably. The major component is raw materials 63%, followed by electric power 8%, labor 5%, maintenance including refractories 4%, electrodes 2%, dust disposal 1.4%, oxygen usage 1%, and the balance fixed costs.

**Special Features**

Modern furnaces are equipped with a variety of features to increase production rates, reduce heat times, and lower operating costs. They include:

- **Ultra High Power (UHP) Transformers.** Power levels of 800 to 1000 kVA/ton are being installed.
- **Water-cooled sidewalls and roofs to reduce refractory costs.**
- **Oxy-fuel burners to supplement heat input and improve melting efficiency.**
- **Oxygen injection for cutting scrap and decarburization to reduce refining time.**
- **Lime injection to reduce processing time and heat loss.**
- **Foamy slags to shield sidewalls and roof from heat radiation from the arcs.** This practice permits the use of maximum available secondary voltage through the use of long arcs with high power factors.
- **Computer control to optimize electric power programming and automatic tap changing based on furnace condition and power demand.** More complex systems provide control of metallurgical parameters (tap temperature and timing of process events), data logging, and least-cost charge calculations, etc.

Arc stability is an important factor in the operation of an electric arc furnace. At the beginning of the melting period, power input is limited by unstable arcs which can also cause flicker in the primary voltage line. Flicker is of concern with increasing transformer power. However, most new UHP meltshops are equipped with static VAR generators for this reason. Also, flicker is reduced significantly when a dc EAF is used to melt steel.

Additional state-of-the-art developments currently being introduced to improve furnace performance as well as steel quality include:

- **Eccentric bottom tapping to reduce tap times, reduce temperature losses, and avoid slag contamination in the ladle.**
- **Oxygen and carbon injection to provide additional heat from oxidation of carbon.**
- **Coated/water-cooled electrodes to reduce electrode consumption.**
- **Scrap preheating to recover energy from furnace waste gases.**
- **Single electrode dc furnaces to reduce electrode consumption and flicker.**

In summary, modern electric arc furnace steelmaking is typified by:

- **Productivity in excess of 100 tons/hr.**
- **Steel scrap and DRI as a raw material.**
- **Separate ladle refining furnace that allows the EAF to be a melter only.**

TechCommentary
The Electric Power Research Institute (EPRI) conducts a technical research and development program for the U.S. electric utility industry. EPRI promotes the development of new and improved technologies to help the utility industry meet present and future electric energy needs in environmentally and economically acceptable ways. EPRI conducts research on all aspects of electric power production and use, including fuels, generation, delivery energy management and conservation, environmental effects, and energy analysis.

The EPRI Center for Materials Production (CMP) is an R&D application center funded by The Electric Power Research Institute and operated by Carnegie Mellon Research Institute, Carnegie Mellon University. CMP is a service of the Industrial and Agricultural Technologies and Services Business Unit of the Customer Systems Group of EPRI. The mission of the Center is to discover, develop, and deliver high value technological advances through networking and partnership with the electricity industry.

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For additional copies of this TechCommentary call ECAC 1-800-4320-AMP.

Key Words: Electric Arc Furnace

Applicable SIC Codes: 3312,3325

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