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techcommentary

Melting Technologies for Aluminum and Other Nonferrous Metals

Introduction

Electric resistance and induction melting processes have emerged as promising technologies in the nonferrous metal industry. Metal processing is an energy intensive industry, consuming 365 trillion BTUs annually. Primary smelters extract raw material from the earth and process the material until it is transformed into a usable material. Secondary processors take the refined material, clean scrap, and recycled scrap to make a finished product.

Electric-powered melters are reshaping how secondary processors conduct business. As foundry companies replace or upgrade fossil-fueled melters, many metal producers are installing electric-powered melters, such as induction and reverberatory furnace, because of their energy efficient melting, increased yield of metal, quicker melt times, and reduced operating costs (Table 1). The focus of this article is to highlight four prominent electric-powered technologies in use in the nonferrous metal melting process.

Figure 1. Tapping a 30,000 kg capacity channel induction furnace

Table 1
Comparison of Electric and Natural Gas-Fired Furnaces for Melting Aluminum

Furnace Type	Heat Source	Normal Furnace Capacity	Metal Loss**	Fuel Consumption Btu/lb	kWh/lb	Thermal Efficiency
Crucible	NG Flame Type	250–2500 lb.	3–5%	300–7000	(0.9–2.0)***	7–17%
Crucible	Electric Resistance	250–2500 lb.	<1%	(854–921)	0.23–0.27	57–61%
Reverberatory Wet Bath	NG Flame Type	2–20 tons	3–5%	1200–1500	(0.35–0.44)	33–42%
Reverberatory Wet Bath	Electric Resistance	2–20 tons	<1%	(638–819)	0.2–0.24	64–75%
Induction Coreless	Electric	0.5–30* tons	<1%	(638–819)	0.2–0.24	55–65%
Induction Channel	Electric	2–30 tons	<1%	(638–819)	0.2–0.24	70–75%

* Comparisons in this table are for heating aluminum alloys from ambient temperatures to furnace temperatures prior to pour; metal losses and energy required for melting will vary depending on the melting temperatures and alloy group. Losses shown for natural gas are for luminous flame-type burners.
** ( ) Equivalent Value
*** Line frequency, smaller sizes available for medium frequency furnaces.

Background

Production of nonferrous metals (aluminum, zinc, copper, magnesium, lead, and various alloys) has increased steadily over the past decade, after slowing down in the 1970s and '80s. Pacing the increased demand for lightweight materials for transportation and manufacturing use, aluminum is predicted to enjoy annual shipment increases of about 4% over the next 8 years, while magnesium shipments are expected to increase 15% annually over the same period. In 1997, aluminum and other nonferrous metals represented one-fifth, by weight, of the total castings produced in the U.S.

Currently, the nonferrous metals casting industry employs about 94,000 people in 1,650 establishments in the United States. Combined, these facilities shipped products valued at over $10.5 billion in 1996. The aluminum and nonferrous casting industry is centered in the Midwest. Fully one-half, by value, of casting shipments in 1996 were from Ohio, Wisconsin, Michigan, Indiana, and Illinois (Table 2). These five states also accounted for almost half the casting jobs.

Major end-users of nonferrous metals include manufacturers in the automotive, aerospace, marine, construction, farm, machine tool, and appliance industries (see sidebar).

Trends and Development

Demand for lightweight cast products has fueled production growth in the nonferrous metal market. According to the American Foundry Society, more than 90% of all manufactured goods and capital equipment use metal castings as engineered components or rely on castings for their manufacture. For example, in 1980 a domestically produced car used an average of 600 pounds (272 kg) of cast iron. In 1999, the average per vehicle dropped to 325 pounds (147 kg). The automotive industry expects that by 2006, this average will drop down to 230 pounds (104 kg). Lightweight nonferrous products are replacing heavy ferrous products, providing comparable structural qualities and reducing mass. Between 1977 and 1998, the proportion of the average vehicle's weight made up by magnesium increased 550%, aluminum's proportion increased 126%, and plastic's share of the vehicle's overall weight increased 50%—all while steel's proportion decreased 13%.

Production increases in the nonferrous metal industries can be attributed to increases in capacity at existing facilities rather than the construction of new facilities. Increased production occurred through improved process control, including more efficient melting technologies and improved material quality. Electric resistance and induction melting is fast, flexible, accurate, and easily automated. More prefer electric melting to fossil-fueled melting because of higher-quality metals, reduced metal loss, and lower operating costs.

Table 2
Value of Shipments and Employment for Top Five Nonferrous Castings Producing States, 1996

State	Value of Shipments ($Millions)	Number of Employees
Ohio	$1,435	12,400
Wisconsin	$1,184	8,600
Michigan	$1,096	8,900
Indiana	$918	5,700
Illinois	$650	6,300
U.S. Total	$10,519	93,900

Electric Melting Technologies

For each of two different electric melting technologies, two varieties are presented. Electric resistance furnaces include crucible and reverberatory varieties and induction furnaces include coreless and channel types.

Electric Resistance Furnaces

Electric resistance furnaces use silicon carbide, graphite, or metal resistance elements to radiate heat into the metal. Radiant heat melts the material and maintains a constant temperature. There are two types of electric resistance

Applications

Typical applications for melting electrotechnologies include:

Aluminum

- **Automotive**
  Engine blocks, housings, pump parts, wheels
- **Aerospace**
  Doors, seats, lugs, brakes, housings, pump parts, wheels
- **Marine**
  Engine parts, propellers, pumps, hull parts, valves
- **Construction**
  Bases, supports, power tools, pumps, compressors
- **Farm**
  Pumps, tractor parts, implement parts

Copper & Brass

- **Marine**
  Propellers, pumps, fittings, valves
- **Construction**
  Plumbing fixtures, fittings, knobs, locks, switch parts
- **Machine Tool**
  Motor contacts and brushes, bearing parts, pump brushes
- **Appliance**
  Contacts, bearing parts, pump parts, pipe fittings

Lead

- **Automotive**
  Battery plates and terminals
- **Other**
  Plates, weights, bearings, ballast

Zinc

- **Automotive**
  Trim parts, handles, locks
- **Appliance**
  Trim parts, supports, lugs, bases, cases, and bearings

Magnesium

- **Automotive**
  Wheels, cases, covers
- **Aerospace**
  Wheels, cases, covers, valves, seats, avionics

NAICS codes included in the nonferrous metal industry include:

- 331521—Aluminum Die-Casting Foundries
- 331522—Nonferrous (except Aluminum) Die-Casting Foundries
- 331524—Aluminum Foundries (except Die-Casting)
- 331525—Copper Foundries (except Die-Casting)
- 331528—Other Nonferrous (except Die-Casting)

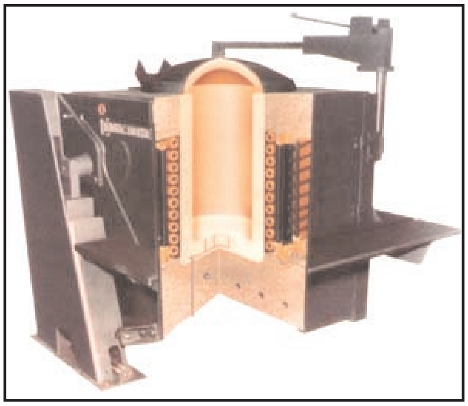

Figure 2. Crucible furnace

melters: crucible furnace and wet-bath reverberatory furnace.

A crucible furnace uses either a silicon carbide or graphite crucible to hold the molten metal. The type of crucible that is used depends on the purity of the melt and type of production. The crucible is surrounded by resistance elements and encased in ceramic refractory. Radiant heat is conducted through the walls of the crucible and ultimately melts the metal. Thermal efficiency is high because this design prevents heat loss due to convection or radiation.

Crucible furnaces are ideal for producers with small production volumes (250 to 2500 pounds) or who need to switch between alloys. These smaller furnaces, however, require higher melt times.

Reverberatory furnaces are normally used for continuous melting operations where large volumes are processed. These furnaces can handle 2 to 20 tons and are easily designed to match a producer's production volume. With wet-bath reverberatory furnaces, solid metal is introduced at a charging well into a molten bath at one end of the furnace. The center portion is sealed off from the charging and delivery ends by a submerged gate, therefore, preventing turbulence and fluing.

Wet-bath reverberatory furnaces have gained acceptance over dry-bath reverberatory furnaces because of lower than average metal loss. Because reverberatory furnaces consume large amounts of electricity, producers must consider operating these furnaces in off-peaks hours.

A recent development in melting involves the use of a large, linear motor inductor installed under the reverberatory furnace bottom, which provides a low frequency moving magnetic field. The moving magnetic field causes an induction current to flow resulting in a stirring action within the bath. The electromagnetic stirring creates a homogeneous melt and higher quality castings. The electromagnetic stirring also improves worker comfort because workers no longer need to work through open furnace doors.

Crucible and reverberatory furnaces are excellent for holding molten metal. The main advantages include:

- Better metal quality
- Increased yield
- Low metal porosity
- Low inclusions
- Better temperature control
- Better plant air quality with lower emissions of particulates, hydrocarbons, and carbon monoxide
- Quieter operation
- Lower plant ambient temperature

The main disadvantages of crucible and reverberatory furnaces are:

- Do not tolerate cleaning
- Metal splashing can damage resistance elements
- High demand requirements make on-peak melting expensive

Induction Furnaces

Induction furnaces induce an electric current in the electrical conducting charge material to be melted. This is accomplished by electromagnetically coupling the charge with the coil carrying an alternating current. The current in the coil induces eddy currents in the charge, which heats and melts the metal. There are two types of induction furnaces: coreless furnace and channel furnace.

The coreless furnace has a refractory shell surrounded by the coil. The metallic charge in the furnace acts as a single-turn secondary transformer winding. When the power is applied to the coil, heat and stirring energy are generated in the melt by eddying currents. When the metal melts, agitation continues to occur due to electromagnetic forces. The stirring action is inversely proportional to the square root of the frequency and directly proportional to the power applied. Frequency and power levels can be changed to control mixing and melting rates. Coreless furnaces are classified as either line (60 Hz), medium (200–1200 Hz), high (over 1200 Hz), or variable frequency units.

Coreless furnaces are best used for melting turnings or clippings and are best suited for simple charging and pouring. The main advantages of coreless furnaces are:

- The furnace can be completely emptied to change an alloy
- Furnaces can be sized to meet melting needs lowering capital and building costs
- Coreless furnaces are very efficient (55 to 80 %) as compared to fossil-fueled furnaces (7 to 50%).

The main disadvantage of a coreless furnace is that refractory cracks can cause premature lining failure.

The channel furnace uses an inductor as its energy sources. The inductor consists of a water-cooled coil embedded in refractory. A channel is formed in the refractory through the coil and this channel forms a continuous loop with the metal in the main part of the furnace. Hot metal in the channel circulates into the main body of the metal in the furnace and is replaced by colder metal. Channel furnaces are extremely energy efficient and are favored for holding melted metal.

The main advantages of channel furnaces include:

- They have a higher electrical efficiency than a coreless furnace
- Extremely effective at mixing ensuring a homogenous heat
- Potentially large energy savings when compared to a reverberatory furnace
- Highly energy efficient (70 to 80%)

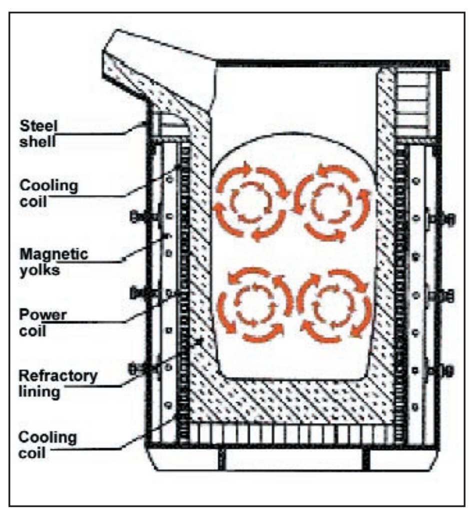

Figure 3. Cross section of large coreless induction furnace

The main disadvantage of a channel furnace is that some alloys can cause refractory cracks resulting in lower reliability and higher maintenance costs.

Some operators use coreless furnaces at night, during off-peak power rates to melt large amounts of metal then hold the molten metal in channel furnaces for casting during normal higher power rate daytime operations. A number of foundries have combined off-peak melting with interruptible rates to achieve energy cost savings. However, operators need to carefully analyze their operations to effectively evaluate the potential costs and benefits of this strategy. If this strategy is impractical for a particular foundry, then a simple load control program to manage melting, drying, and reclamation operations to control electric demand may be effective in controlling energy costs.

Process Control Technologies

By replacing low frequency induction furnaces with high or variable frequency furnaces, stray current and other heat losses can be reduced with improved production rates and product quality. Additionally, the replacement of older power supplies with solid state supplies can also achieve lower production costs and higher production rates. In recent years, power density demand has increased in order to decrease the time required to melt metals.

High technology solutions have improved operating conditions for non-fossil fuel furnaces. Microprocessors now monitor several operating and equipment conditions simultaneously, allowing the operator to adjust conditions for optimum performance. Depending upon the user's need, microprocessors can even automate melting operations. Fiber optics is gaining acceptance in detection systems as well because it eliminates signal interference common with copper wiring. With fiber optics, operators can be assured that incoming data are accurate. Both trends lead to more efficient melting, improved metal quality, and reduced operating costs.

Summary

There are a number of factors that favor the use of electric melting technologies in the nonferrous melting industry:

1. The high cost of disposal of spent salts and dross
2. The need for higher productivity
3. The need for higher quality products
4. The need to minimized emissions or pollution control equipment
5. The need to hold heats for longer periods
6. Physical building limitation limit expansion
7. The need to increase metal yields

For Technical Information

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Figures 1 & 3 courtesy Ajax Magnathermic Corp.
Figure 2 courtesy Inductotherm Corp.

Applicable NAICS Codes: 331521, 331522, 331524, 331524, 331528

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