Report of Investigations 9476

Facility for Melting Residues From Municipal Waste Combustion: Design Criteria and Description of Equipment

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UNITED STATES DEPARTMENT OF THE INTERIOR
Bruce Babbitt, Secretary

BUREAU OF MINES

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ILLUSTRATIONS

UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

A	ampere	lb	pound
°C	degree Celsius	lb/ft^3	pound per cubic foot
cfm	cubic foot per minute	lb/h	pound per hour
°F	degree Fahrenheit	mA	milliampere
ft	foot	MHz	megahertz
ft^3	cubic foot	μm	micrometer
gal	gallon	MMBtu/h	million British thermal unit per hour
gpm	gallon per minute	Ω	ohm
hp	horsepower	pct	percent
Hz	hertz	psi	pound per square inch
in	inch	psig	pound per square inch gauge
kHz	kilohertz	s	second
kV	kilovolt	scfm	standard cubic foot per minute
kV•A	kilovolt ampere	st	short ton
kW	kilowatt	V	volt
kW•h/st	kilowatt hour per short ton	V ac	volt, alternating current

FACILITY FOR MELTING RESIDUES FROM MUNICIPAL WASTE COMBUSTION: DESIGN CRITERIA AND DESCRIPTION OF EQUIPMENT

By Alan D. Hartman,[1] Laurance L. Oden,[2] and Jack C. White[3]

ABSTRACT

The U.S. Bureau of Mines, under a Memorandum of Agreement with the American Society of Mechanical Engineers (ASME), established design criteria for a facility to melt residues from municipal waste combustion. This facility, which is available to potential users on a cost-sharing basis, is also applicable to a variety of inorganic waste materials from smelting or melting operations. The design consists of a mechanical feed handling system, electric arc melting furnace, fume-offgas handling system, and thermal oxidizer for final offgas treatment. Screw conveyors and a bucket elevator deliver up to 2,000 lb/h of minus 1-in material to a three-phase electric arc melting furnace. This unique 800-kV•A furnace has a water-cooled shell and roof to minimize interaction of the melt with the refractory lining. The volume of the hearth below the slag taphole is approximately 1.2 st of steel. The furnace is sealed, allowing atmosphere control within the furnace and fume duct by nitrogen or inert gas injection. A jet-pulsed baghouse removes particulate from the offgas and serves as an acid gas scrubber. The clean offgas is heated to 1,800° F for 1 s in a propane-fired thermal oxidizer before being vented to the atmosphere.

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INTRODUCTION

The most widely applied method for the disposal of waste materials, including sludges,.dusts, scales, leachable slags from smelting or melting operations, and residues from the combustion of organic materials including municipal wastes, is to inter the materials in an appropriate landfill. Small quantities of some wastes are encapsulated within Portland cement or sulfur, and then consigned to a landfill. However, landfill disposal of wastes is at best a short-term solution, because landfills are nearing capacity and new landfills are difficult to establish. A promising and technically viable permanent solution to the problem is to melt the waste materials to produce inherently nonpolluting amorphous or crystalline mixtures of inorganic oxide products, similar to slags produced by various metal industries (*1-4*).[4] These products may be useful as aggregate for bituminous or Portland cement concrete, for grit blasting, as road building and construction ballast, and in the manufacture of mineral wool instead of landfill disposal.

In 1984, the ASME Research Committee on Industrial and Municipal Waste asked the U.S. Bureau of Mines about the feasibility of melting (vitrifying) ash residues produced by the combustion of municipal wastes. A demonstration melting test of dry combined bottom ash and fly ash from a waste-to-energy (WTE) facility in Chicago, IL, was conducted by the Rolla Research Center (RORC) of the USBM in Rolla, MO, in 1984.[5] This proof-of-concept trial provided slag and metal phases that were environmentally benign, had a mean density three times greater than the parent residue, and had the potential for several beneficial uses. Similar results were observed in a 1986 full-scale 1-st electric arc furnace test at the Albany Research Center (ALRC) of the USBM in Albany, OR.

An agreement was signed by the ASME and the USBM in September 1990 to conduct scaled-up melting tests in a nominal 1-st electric arc furnace at the USBM ALRC. These melting tests were completed in July 1992 on five combustion residues. The residues consisted of combined dry bottom ash and fly ash from three state-of-the-art mass-burning WTE plants in the northeastern United States, dry combined ash from a multiple hearth (waste water treatment) sludge incinerator, and fly ash from a WTE plant burning refuse-derived fuel (RDF).

The melting program required the design and construction of an electric arc melting furnace having water-cooled shell and roof to cope with the corrosive slags; modification of an existing power supply designed for melting steel to accommodate the higher resistance of the slags; and construction of continuous feeding and fume-offgas handling systems. A summary of the design criteria for the feed system, furnace, and fume-offgas handling system and a description of each follows.

DESIGN CRITERIA

The design criteria for the equipment that make up the furnace system consist of the following specifications.

Feed system:

1. Continuous feed rate of 2,000 lb/h for municipal waste combustion residue with a bulk density of 80 lb/ft^3.
2. Capability to convey material passing a 1-in screen.

Furnace and power supply:

1. Electrical voltage measured phase-to-phase at the furnace electrodes in the range of 240 to 350 V and full load amperage of 2,000 to 2,500 A.
2. Melt rate up to approximately 2,000 lb/h of material having an enthalpy requirement of 800 kW•h/st.
3. Open-arc, submerged-arc, or intermediate modes of operation.
4. Hearth volume below the slag taphole of approximately 5 ft^3.
5. Option to tap the furnace slag taphole intermittently or continuously.
6. Intermittent tapping of metal and the ability to empty the furnace through the bottom of the hearth.
7. Capability to granulate up to 500-lb batches of slag product with a high-pressure water jet unit.
8. Capability to operate under ambient air or inert gas (N_2) atmosphere. Nitrogen delivery rate up to 150 scfm.

Fume-offgas handling system:

1. Monitors in the fume duct to indicate O_2 concentration and temperature of gas entering the baghouse.
2. Capability to maintain the O_2 concentration in the fume duct below 6 pct, i.e., below the flammability range for CO by adding N_2.
3. Capability to add or remove heat from the fume-offgas to maintain the temperature above the dew point, but below the destruction temperature of the baghouse.
4. Baghouse capacity to remove 99 pct of particulate greater than 1 μm at a total flow rate of 150 scfm.

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[4] Italic numbers in parentheses refer to items in the list of references at the end of this report.

[5] Results of RORC and ALRC tests are available from Paul C. Turner, Bureau of Mines, Albany, OR.

5. Acid gas absorption provided by injecting up to 100 lb/h hydrated lime with the carrier gas, N_2, into the baghouse.

6. Offgas incineration before exhausting to the atmosphere to provide 1 s residence time at 1,800° F for flow rates up to 250 scfm.

DESCRIPTION OF EQUIPMENT

A flow diagram for the feed handling, melting, and fume-offgas handling systems is shown in figure 1.

FEED HANDLING

Feed material is transferred by overhead crane, equipped with a crane scale, into a 60-ft^3 receiving bin, which uses twin counter-rotating 12-in-diameter screws to feed a bucket elevator. The bucket elevator lifts the feed material 17 ft to a 10-ft^3 meter bin, which discharges via twin counter-rotating 6-in-diameter screws to a 6-in-diameter splitter screw. The splitter screw then feeds two 6-in-diameter delivery screws. Each delivery screw then discharges into the furnace through a pneumatically activated splitter gate that divides and routes the feed to two separate ports in the furnace roof. Feed is thereby uniformly admitted into the furnace through four ports in the roof. The feed system can deliver up to 2,000 lb/h to the furnace of material with bulk density of 80 to 100 lb/ft^3. Control of the feed system can be either automatic or manual. Figure 2 is a floor-level view of the feed-handling system, designed by Thomas R. Miles, Consulting Design Engineers, Portland, OR (*5*).

MELTER

Electric Arc Melting Furnace

An existing tilting Lectromelt[6] size ST (nominal capacity 1 st of steel) refractory-lined furnace shell and roof were replaced by a stationary furnace having a water-cooled shell, water-cooled roof, and air-cooled bottom (fig. 3). The existing electrode arms and roof supports were unchanged. Figure 4 is a vertical section of the furnace shell and roof showing upper and lower water trough placement, air plenum for bottom cooling, taphole locations, slag launder, and placement of the furnace with respect to

[6]Reference to specific products does not imply endorsement by the U.S. Bureau of Mines.

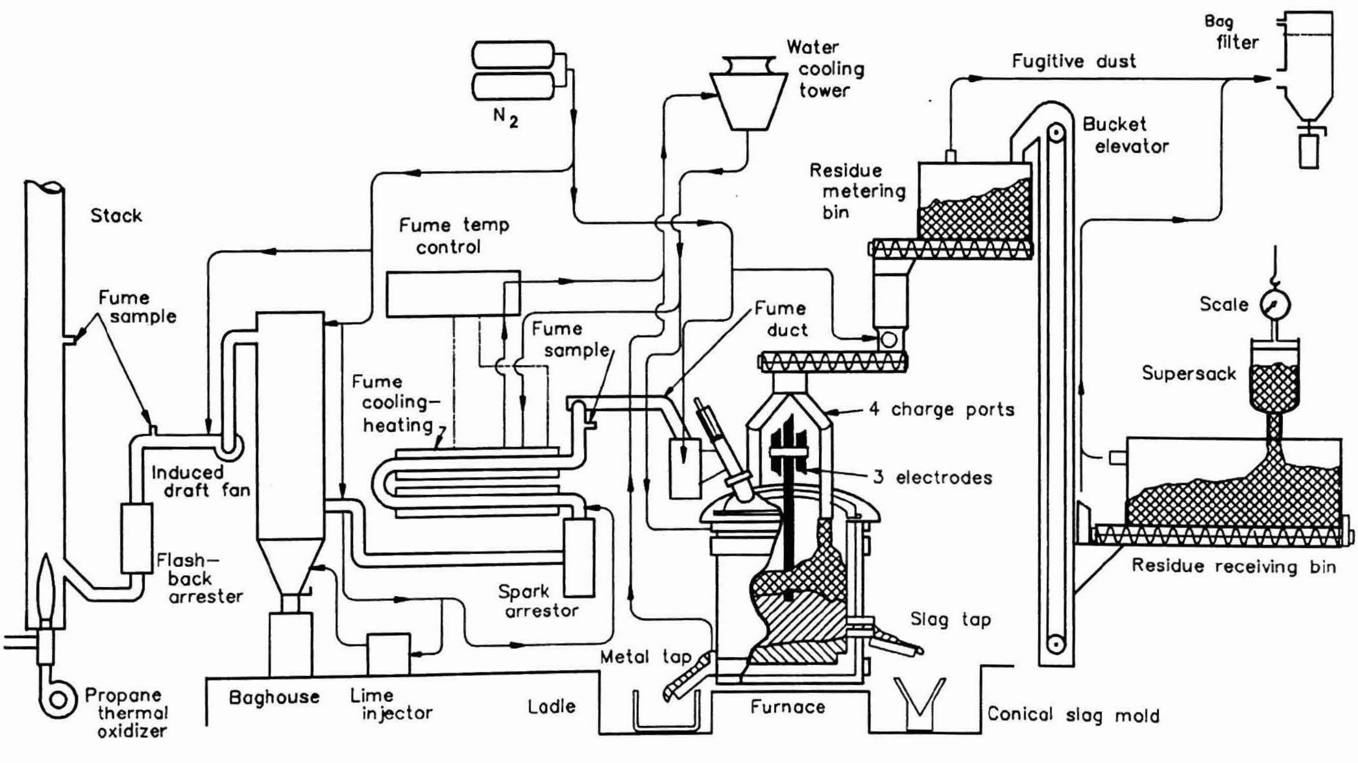

Figure 1.—Process system flow diagram.

floor level. Three carbon steel ground straps (2 in wide by approximately 1/16 in thick) were welded to the inside bottom of the shell in a triangular array prior to placing the refractory lining in the shell. These straps were worked between the bricks during construction of the hearth to provide a circuit-to-ground path between each pair of electrodes. The furnace shell then was securely grounded on the outside with 00 size copper wire. A concrete pedestal supports the furnace between two rectangular pits each 3 ft 6 in deep by 5 ft 10 in wide by 7 ft long.

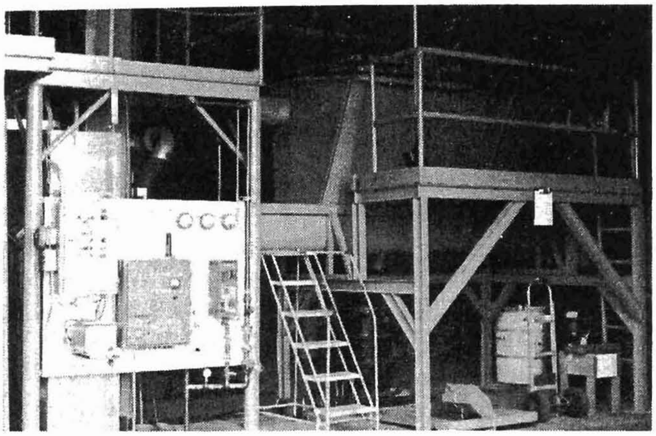

Figure 2.—Floor-level view of feed-handling system.

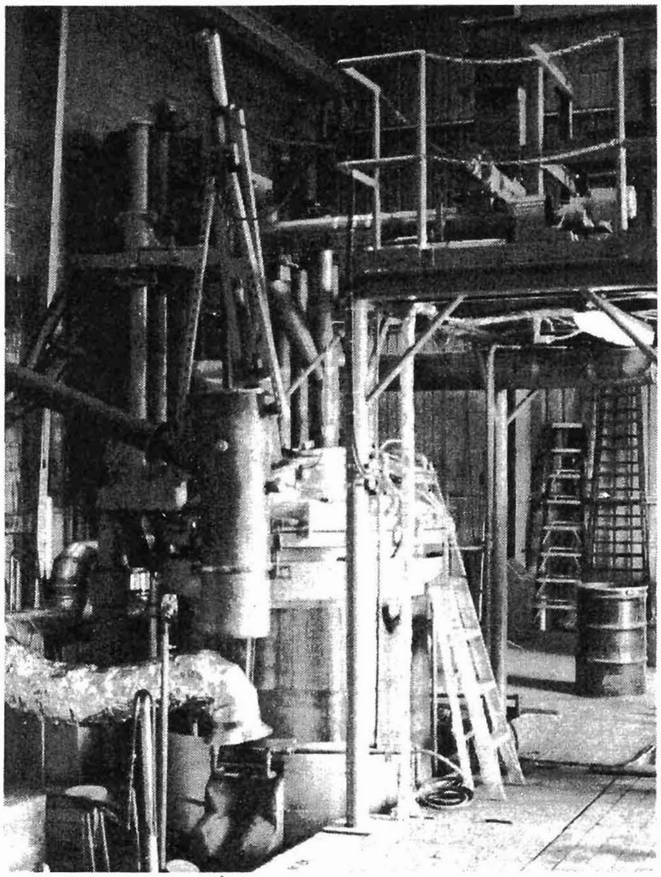

Figure 3.—Electric arc melting furnace showing fume settling chamber above metal taphole.

Figure 5 is a top view of the furnace and domed carbon steel roof identifying the numerous ports and water passages in the roof. The complex roof is designed with a circular water passage near the outer edge to protect the roof-to-shell seal, which consists of two annular channels in the shell and two knife edges in the roof. The inner channel contains fine sand, and the outer channel contains a silicone elastomer. About 70 pct of the exterior surface

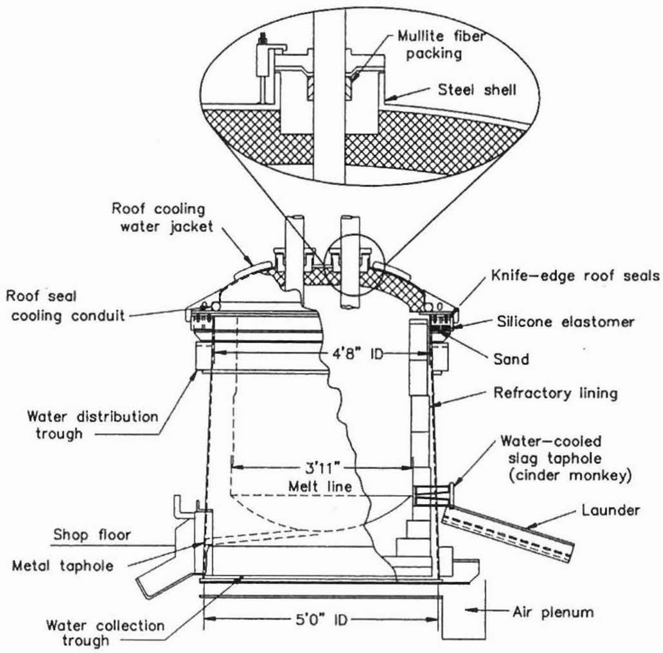

Figure 4.—Electric arc melting furnace cross-sectional schematic.

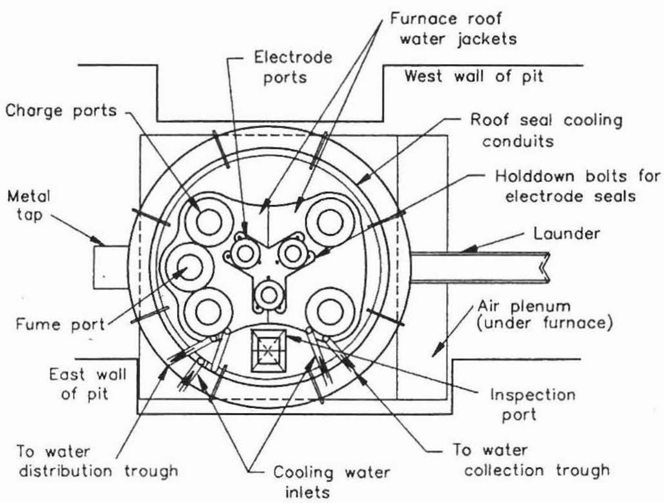

Figure 5.—Top view of furnace and roof.

of the roof encompassing the electrode, feed, and exhaust ports is effectively water cooled by two water jackets, as shown in the figure. The roof is lined with 4 in of NARPHOS 85P plastic refractory (85 pct alumina) manufactured by North American Refractories Co., Cleveland, OH. This material was selected for ease of placement (owing to the complexity of the roof) and for its ability to withstand the high temperatures anticipated during open-arc operation and the corrosive nature of the condensable fume within the furnace.

The three central ports in the roof accommodate 4-in-diameter graphite electrodes manufactured by Union Carbide (UCAR) Carbon Co. Inc, Cleveland, OH. The ports are 8-1/4 in diameter, extend about 2 in above the dome, and occupy the apexes of an equilateral triangle with 11-1/4-in sides. The roof refractory was not extended into the vertical extensions of the electrode ports; instead, two-part ceramic ring seals cast from Cast-O-Last G Ad-Tech from Harbison-Walker Refractories, Pittsburgh, PA were fitted into the annular space between electrode and roof port to minimize gas leakage around the electrodes. A completed electrode seal consists of a ceramic-fiber gasket between a shelf on the bottom seal and the top of the roof port, and ceramic-fiber packing within the annular space between the bottom and top parts of the seal. The upper part of the seal was clamped to the roof to compress the ceramic packing around the electrode (fig. 4).

The four charging ports in the roof are arranged in a rectangular array to distribute the feed uniformly to the furnace. Each charging port is 10-1/4 in. in diameter. The roof refractory does not extend into the vertical extensions of the charging ports. Ceramic seals, similar to the electrode seals, also are installed in the charging ports.

Fume and offgas exit the furnace through the circular exhaust port in the roof. The roof refractory extends into the 10-in-diameter exhaust port to decrease the inside diameter to 6 in. A 10-in-square inspection port is fitted with a door that can be opened to provide access to the furnace. The roof refractory also extends into the inspection port to provide a square opening with 4-in sides.

Furnace Refractories

The carbon steel furnace shell is 65 in high and tapers from 60-in ID (inside diameter) at the bottom to 56-in ID at the top. Refractory placement within the shell and roof is indicated in figure 6. The bottom of the shell is lined with 5 in (two courses) of chromic-oxide—alumina-bonded 90-pct alumina super-duty firebrick (Ruby) straight bricks from Harbison-Walker Refractories. Five courses of Ruby key bricks shape the hearth and form the sidewall up to the steel shelf 28 in above the bottom, which is approximately 7 in above the slag taphole. One inch of dry phosphate-bonded silicon carbide (SiC) ramming mix from

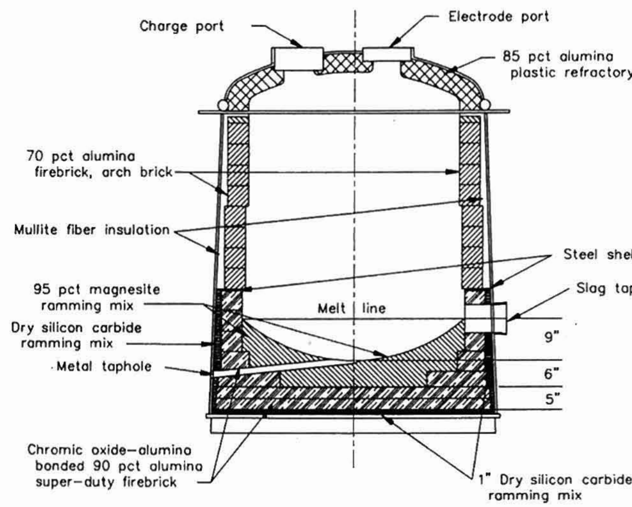

Figure 6.—Refractory placement in furnace shell and roof.

the Norton Co., Worcester, MA was placed between the steel bottom and the first course of Ruby straight bricks to improve heat transfer to the bottom. This ramming mix, about 1 in thick, also was placed between the Ruby key bricks and the sidewall for the same reason. The upper sidewall is lined with 4-1/2-in GM 70 DE (70-pct alumina) insulating arch firebrick from North American Refractories Co. One-inch Fiberfrax batting from the Carborundum Co., Niagara Falls, NY was placed between the sidewall and the arch brick for additional insulation. At midheight the finished inside diameter of the furnace is about 46 in. The hearth is rammed to a depth of 6 in at the center with Permanente 165 AF (95-pct MgO) ramming mix from National Refractories, Oakland, CA.

The furnace is tapped for metal and drained through the 1-1/2-in-diameter hole that was built into the furnace lining in the bottom center of the hearth during construction. The slag taphole, termed the cinder monkey, is grouted in place with the MgO ramming mix. The cinder monkey is a welded, water-jacketed copper structure 6 in diameter by 10 in long with a 1-in central hole designed to tap slag continuously at rates up to 2,000 lb/h. The design capacity of the hearth, which finished to 48 in diameter by 9 in. deep at the center, is approximately 5 ft^3 and will accommodate about 2,600 lb of steel or 800 to 1,000 lb of slag.

Furnace Cooling

The base of the furnace is cooled by air flowing at approximately 1,300 cfm through a plenum formed by six 4-in-high I-beams upon which the furnace rests. The furnace shell, roof, cinder monkey, slag launder, metal taphole collar, and power supply transformer, as well as the electrode arms, cables, and clamps, are water cooled.

Cooling water is pumped to the furnace from a 1,500-gal cool water sump by a 15-hp centrifugal pump. The furnace shell is cooled by a curtain of water (50 gpm) that cascades down the wall from an annular distribution trough near the top of the shell. All cooling water is collected at the base of the furnace in a trough and is returned by gravity to a 1,500-gal warm water sump through a 6-in polyvinyl chloride (PVC) line. Water is pumped from the warm water sump to a Marley Model NC-111 cooling tower of crossflow, induced draft design (*6*). The cooling tower supplies up to 150 gpm of water at 75° F with 142° F maximum return temperature and 70° F wet bulb temperature. Figure 7 is a circuit diagram for cooling water indicating maximum anticipated flow rates.

City water is available for emergency cooling in case of general power failure or malfunction of the circulating pumps. The most critical application of cooling water is the copper cinder monkey, which is in direct contact with molten slag while the furnace is operating. All other applications likely will not be damaged by stoppage of water if furnace power also is stopped. A flowmeter in the water circuit to the cinder monkey de-energizes and opens the automatic valve in the city water line if the flow rate from the cooling tower decreases below 20 gpm in that circuit.

Power Supply, Control, and Monitoring

An existing three-phase power supply designed for melting steel was altered to provide an increase in voltage. This alteration provided a higher power input without requiring an increase in the depth of the electrodes into the melt. Alteration consisted of the addition of three single-phase 250 kV•A transformers configured with the primary circuit of each 250-kV•A transformer in parallel with the appropriate phase of the 800-kV•A transformer. The secondary circuit of each 250-kV•A transformer was connected in series with the appropriate phase of the secondary circuit of the 800-kV•A transformer (fig. 8) (*7*). Nameplate specifications for the 800-kV•A and 250-kV•A transformers are as follows:

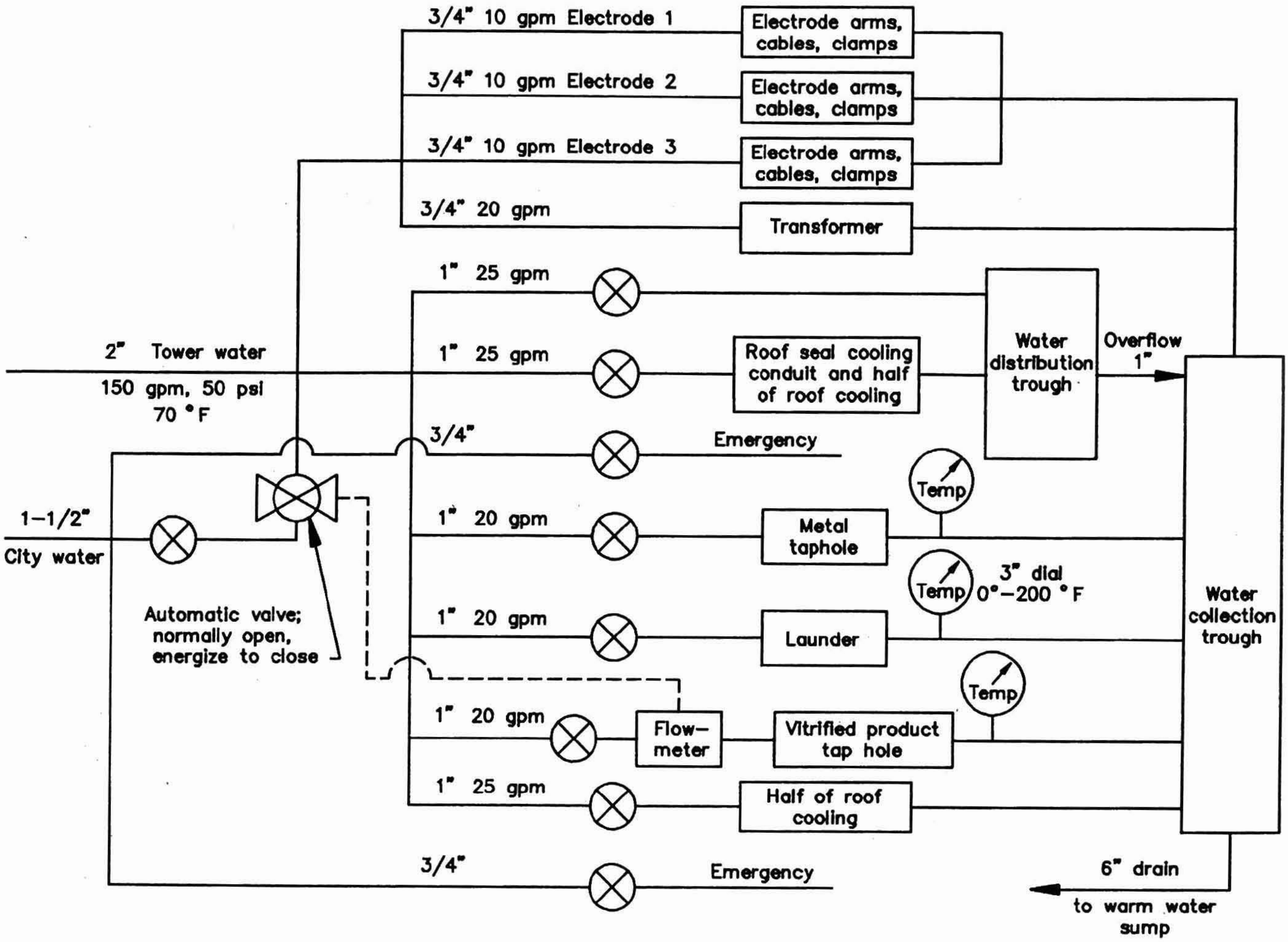

Figure 7.—Furnace and transformer cooling-water circuit diagram.

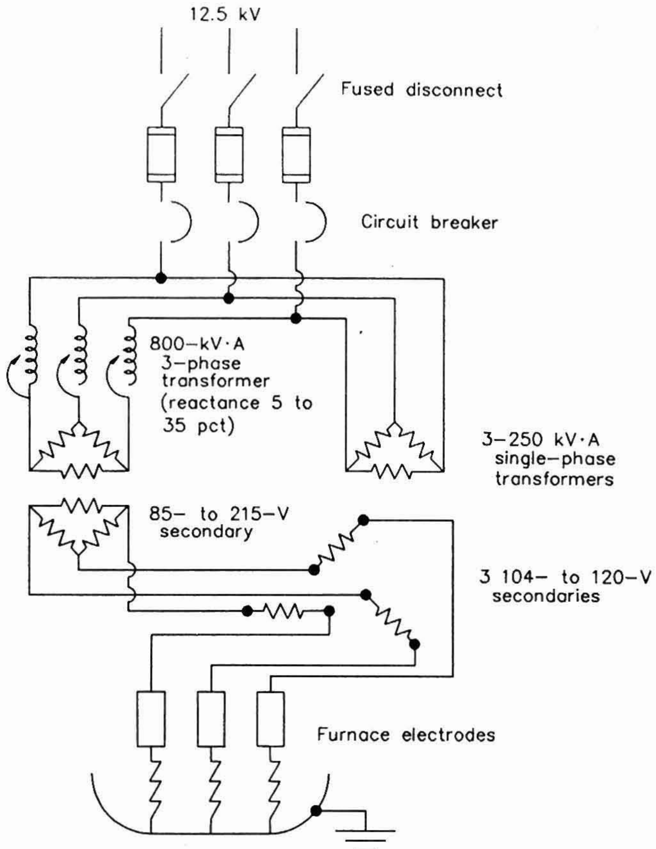

Figure 8.—Electric arc melting furnace power system electrical circuit.

Pennsylvania three-phase furnace transformer specification 8662:

Voltage rating	11,500 - 215 V ac,
Capacity rating	800 kV•A at 55° C rise,
Class	OW,[7]
Frequency	60 Hz,

Secondary current rated at 2,150 A at 215 V,
Reactance of transformer at 215 V full capacity = 5 pct,
Reactance of reactor at full capacity current = 30 pct,
Reactance of transformer and reactor at 215 V full capacity = 35 pct.

General Electric SPIRAKORE 250-kV•A single-phase transformer nameplate specification:

Voltage rating	14,400 - 120/240 V ac,
Capacity rating	250 kV•A at 55° C rise,
Class	OA,[8]
Type	HS,[9]
Frequency	60 Hz,

Secondary current rated at 2,080 A at 120 V,
Reactance of transformer at 120 V = 6.1 pct,
Impedance at rated volts = 0.1 pct.

The 12,500-V primary connections were used on the 800-kV•A transformer, and the 14,400-V primary connection was used on the three 250-kV•A transformers. The 800-kV•A transformer was configured internally to provide the following output voltages and impedance:

Tap A — 182 V at 1/2 total reactance, R,
Tap B — 137 V at 1/2 R,
Tap C — 124 V at 1/6 R,
Tap D — 95 V at 1/6 R.

These settings resulted in the average secondary open-circuit voltages shown below, as measured at the electrodes in volts (*8*):

	Phase-to-phase	Phase-to-ground
Tap A	352	192
Tap B	304	168
Tap C	256	145
Tap D	239	134

Real-time electrical current and voltage referenced to ground are recorded for the three phases during furnace operation to compare real-time electrical parameters with the analog instruments on the control panel and to provide information for future analysis of arc stability. The voltage signals are obtained from the bus bars leading to the electrodes by using divide-by-40 voltage dividers. Currents are obtained from 0.00005-Ω shunts on the bus bars. All signals are transmitted to waveform recording equipment by Dymec 1-MHz analog fiberoptic links to achieve electrical isolation (*9*). A LeCroy 6810 digitizing system records electrical waveforms from the primary and secondary sides of the transformers (*10*). Data acquisition rates can be varied at 50, 100, and 500 kHz. Data are to be transferred to a personal computer for analysis and graphing.

SLAG TAPPING AND GRANULATION

Slag is tapped continuously from the water-cooled copper taphole (cinder monkey) into 1,000-lb-capacity conical cast iron molds. The slag pit accommodates two molds, and the slag stream can be routed to either mold by moving the slag launder. Molds are moved by an overhead crane equipped with a crane scale. Slag to be granulated is tapped into a preheated, refractory-lined ladle and transferred to the granulator.

The granulator consists of a refractory channel that directs a small stream of molten slag from the ladle into a jet of water moving within an 8-ft-long by 1-ft-high by 1/2-ft-wide 18-gauge stainless steel trough. Water is supplied from a pump by a 1-1/2-in pipe entering a variable flow nozzle. The water and granulated slag exit the trough into a holding and settling tank (fig. 9).

[7]Manufacturer's specification—not defined.
[8]See footnote 7.
[9]Ibidem.

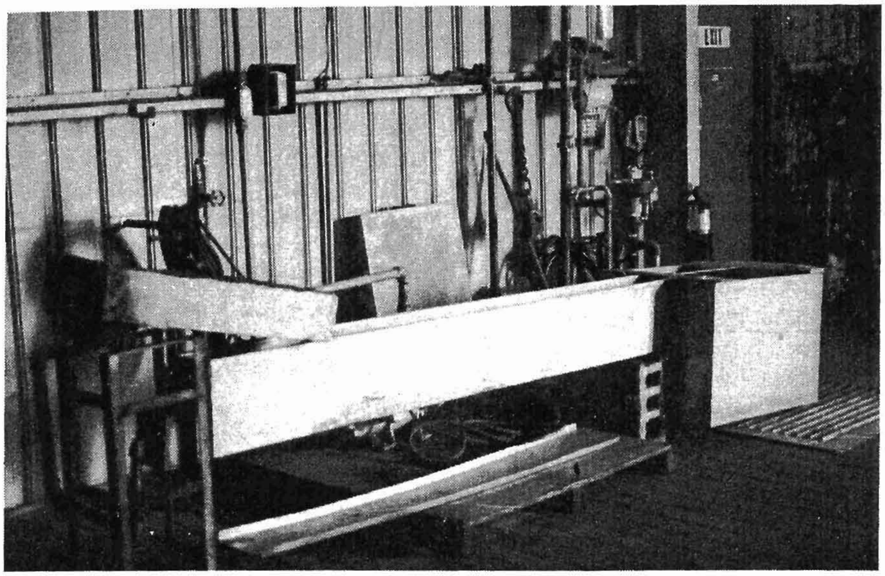

Figure 9.—Slag granulator.

FUME-OFFGAS HANDLING

Ducting, Heat Exchanger, Baghouse, and Thermal Oxidizer

Fumes and gases exit the roof of the furnace via a 6-in-diameter duct into a 14-in-diameter settling chamber to capture large particulate material. A hydraulic ram with circular scraper blade, fastened at the top of the near-vertical duct section nearest the roof, is used to clear accumulations of particulate or condensate within the duct. After an approximate 20-ft run from the settling chamber, the offgas enters a water-jacketed double-pipe heat exchanger that either heats the cool gas during startup to prevent condensation, or cools the hot gas during continuous operation to deliver gas in the temperature range of 250° to 400° F to the baghouse. Hot or cold water for the heat exchanger is provided by a SuperTrol temperature control unit manufactured by Enercon Systems Inc., Elyria, OH (*11*). The SuperTrol, which is rated at 36 kW, provides 120 gpm water at 180° to 250° F to the heat exchanger for heating or cooling.

The offgas then enters a spark trap to capture incandescent particles and proceeds from the spark trap to a baghouse containing 21 4-in-diameter by 10-ft-long Gortex membrane-Teflon fluorocarbon polymer B, fiberglass fabric bags. The full complement of bags in the baghouse is 49, but only 21 bags were required for the listed design criteria (*12*). The bags are cleaned with a back pulse of 100 psig N_2 at field selectable time intervals. Up to 100 lb/h hydrated lime can be injected into the baghouse with the carrier gas, N_2, for acid gas control. A 5-hp variable-speed fume fan, located in-line after the baghouse, discharges the offgas into a thermal oxidizer fueled by propane rated at 2.2 MMBtu/h before exhausting to the atmosphere. The thermal oxidizer is designed to provide 1 s residence time at 1,800° F for gas flow rates in the range 125 to 250 scfm (fig. 10) (*11*, pp. 1-3).

Nitrogen Inerting System

The furnace and fume handling system are operated under an N_2-enriched atmosphere. Liquid N_2 is vaporized and supplied to the following locations at the approximate rates indicated:

Furnace interior — 5 cfm,
Feed system splitter screw — 5 cfm,
Exhaust duct settling chamber — 110 cfm,
Duct between heat exchanger and baghouse — as needed to maintain O_2 <6 pct and temperature <400° F,
Baghouse pulsing unit — as needed,
Fume fan bearings — 5 cfm, and
Lime injector — 10 cfm.

The rate of N_2 injection through two 4- to 20-mA controlled ball valves into the fume duct immediately after the fume cooler is automatically controlled by an O_2 sensor and a temperature sensor (*13-14*). Nitrogen is injected, when needed, to maintain O_2 below 6 pct and the temperature below 400° F. Limiting the O_2 concentration in the offgas is essential to prevent combustion of CO in the fume duct, and the temperature upper limit prevents overheating or burning of the baghouse bags. Additional temperature and pressure sensors are located throughout the system, and their outputs are displayed in a single location for ready reference, as shown in figure 11.

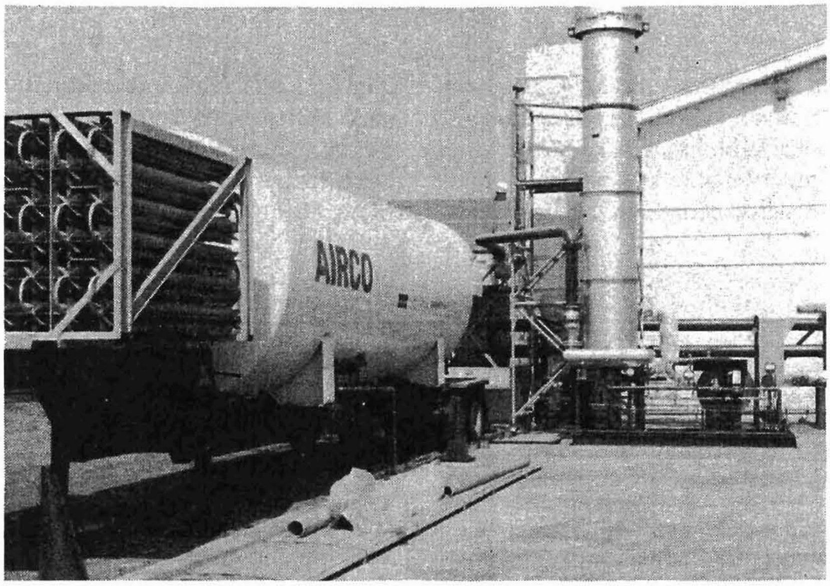

Figure 10.—Fume-offgas handling system consisting of a double-pipe hairpin heat exchanger, baghouse, and thermal oxidizer.

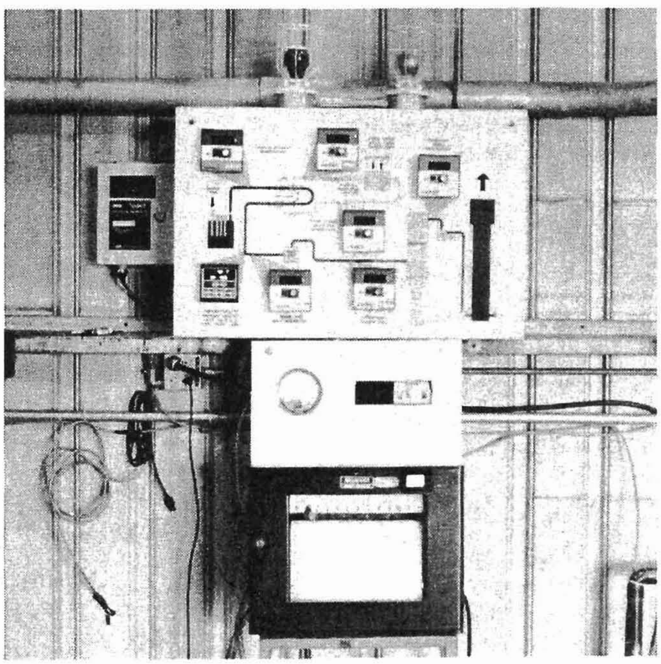

Figure 11.—Oxygen, temperature, and pressure display board.

SUMMARY

Design criteria and a description are provided for a melting facility to convert waste materials such as sludges, dusts, ashes, scales, and leachable slags from smelting or melting operations into nonleachable amorphous or crystalline products. The facility comprises a mechanical feeder, an 800-kV•A three-phase electric arc melting furnace having water-cooled shell and roof, gas-cooling and cleaning apparatus, and thermal oxidizer for final offgas treatment. This unique facility is available to potential users, both public and private, on a cost-sharing basis.

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