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# Commissioning and Operating an Induction Furnace at Zimasco (KweKwe Division) to Melt High-carbon Ferrochromium

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A 6,4 t induction furnace was commissioned at Zimasco (Kwekwe Division) in May 1989 with the object of reclaiming minus 1 mm high-carbon ferrochromium fines that had previously been stockpiled.

Over the years, the Division had stockpiled a large accumulation of fines, which had previously been considered to be a waste product of no market value.

Current arisings are presently accumulating at a considerable rate.

The project marks the first time worldwide that an induction furnace has been used to remelt high-carbon ferrochromium alloy. The results obtained to date confirm that inductive power can be used successfully to melt high-carbon ferrochromium fines. The furnace is now operating close to its design operating parameters.

This paper describes the operating experience from commissioning to the time of writing. Major aspects covered include the training of personnel in the refractory-re-lining procedure, the sintering method, and the furnace melting operations.

## Introduction

Zimasco (KweKwe Division) produces 190 kt of high-carbon ferrochromium (HCFeCr) per annum when running at full capacity. Considerable quantities of high-carbon ferrochromium smaller than 12,5 mm are generated when the initial high-carbon ferrochromium ingots from the electric-arc furnaces are crushed and screened to meet customer's requirements. These fines are subjected to a gravity-separation technique using hydraulic jigs to produce a coarse product (1 to 12,5 mm), which can be sold to a limited market, and a fine fraction (–1 mm). This fine product is stockpiled, and the Division has over the years built up a large stockpile, which represents a serious loss of revenue. The fines can be recycled to the electric-arc furnaces but only at limited rates because of their significant effect on the charge conductivity and furnace temperatures.

The induction furnace project, which is the subject of this paper,was conceived to reclaim the –1 mm high-carbon ferrochromium fines and convert them to a saleable lump product. A 6,4 t induction furnace was acquired in October 1988 and commissioned in May 1989.

## Process Flowsheet

The wet feed material for the induction furnace is transferred from the gravity-concentration plant by road transport. It is then stored and sun-dried on a vast concrete pad. Feed to an induction furnace should be as dry as possible. The moisture levels of the current feed have averaged less than 0,2 per cent. From the pad, the dried feed material is moved either to a strategic storage bunker or to an inground hopper. The strategic storage bunker, which is covered, was designed to allow for continuous feeding operations during the wet season. From the in-ground hopper, the feed material is transferred via a conveyor system to a weigh flask, which is mounted on load cells. The conveyor belt is interlocked to the weigh flask so that the belt will automatically start once the set mass of material in the flask has been depleted. From the weigh flask, the feed material passes through a screw feeder and a vertical feed chute, and then into the furnace.

After the melting process, the crucible is tilted hydraulically, and both the molten alloy and the slag are poured into cast steel moulds. The alloy and slag are cooled in the moulds for a period of 6 hours. The ingot is then stripped off the moulds, and placed on the ground for a further 1,5 hours of cooling. Following this stage, the ingot is placed on a pallet. It is quenched in water for a period not exceeding 4 hours, and then handled and processed in exactly the same manner as other ingots from the electric-arc furnaces.

A materials flowsheet for the smelter is shown in Figure 1, and a diagrammatic flowsheet of the induction-furnace operations is shown in Figure 2.

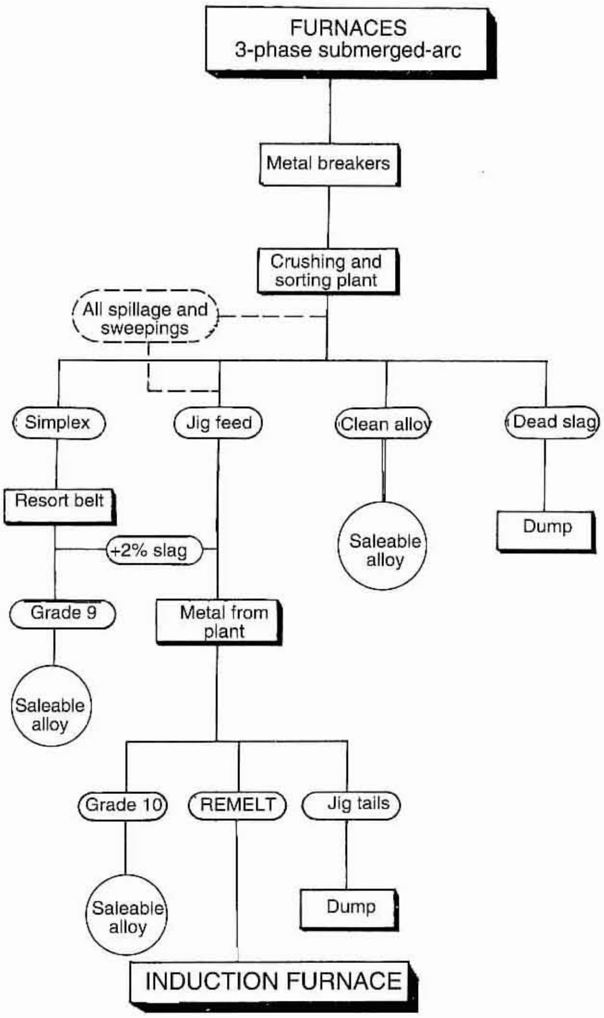


FIGURE 1. Flowsheet of materials to the smelter

## Organizational Structure of the Induction Furnace

The day-to-day functions of the section are coordinated by a foreman who has a line function over the entire shift crew.The foreman is a staff employee who works normal hours. The shift crew, which is headed by a supervisor, works a four-shift system roster on a 24-hour basis. A furnace operator, who reports to the supervisor but has no line authority over the casting-bay crew, is responsible for the panel, melting, and pouring operations. The casting-bay personnel, which include the overhead-crane driver, two crane slingers, and cast-steel mould preparers, are primarily responsible for the mould preparation and the alloy-ingot cooling and quenching processes. A conveyor attendant mans the feed system.

## Training

Following the setting up of an organizational structure for the project, a crew of supervisory and operating personnel was selected from the existing electric-arc furnace labour complement. Since the project was a new one, emphasis during the selection process was placed on experience in panel-room operations and reliability of character. A qualified metallurgist was attached to the project as team leader.

Visits to other induction-furnace operations, both local and overseas, were arranged for the team. The purpose of these visits was to familiarize the team with induction-furnace equipment and operations.

Critical tasks for the operation were identified before the start-up process. Safe job procedures for the tasks were then formulated. A period of 3 months was devoted to training and education of the project team on the written job procedures.

A commissioning engineer from the equipment manufacturers and a refractories specialist from a UK-based company provided valuable information during informal lecture sessions. During the start-up period, a special roster was formulated to afford the four shift-supervisory crews adequate exposure to supervised melting operations. The roster was designed to allow melting and pouring operations to be conducted between 0700 hours and 1900 hours each day. The other 12 hours were allocated to ingot-quenching and mould-preparation activities.

After the furnace had been in continuous operation for about six months, a UK-based induction-furnace operation technician spent a fortnight with the operators to optimize the operational and lining-installation techniques.

## Equipment Design

The induction furnace consists of one 3,5 MW solid-state Inductotherm Power-Melt pack and two coreless tiltable furnace crucibles, with a nominal capacity of 6,4 t each placed side by side. Auxiliary equipment with suitable disconnect arrangements to turn the power on or off to either of the crucibles alternately is also fitted.

Each crucible assembly consists of a separate standing unit, 6,4 m long, 4,26 m wide, and 3,35 m high, placed side by side with steel-sheet enclosures and a steel anti-skid furnace-working deck. The melting units are placed inside these enclosures, complete with water-cooled copper coils, laminated steel shunts, and hydraulic tilting equipment.

Each crucible is fitted with a hydraulically driven swing lid containing an inspection and a feed port fitted with their own manually operated lids. Each crucible is lined with a rammed and spiked dry refractory lining. Figure 3 shows a section through the induction furnace.

The rate of melting of the feed material is about 5,5 t/h, with a 1,5 h pouring cycle. One crucible is used at a time. The furnace is run on a continuous 24 h basis. Currently, a full campaign from start to finish takes about 105,6 h before the refractory lining fails. At that point, the other crucible is brought on line.

The design criteria are as follows:

| | |
|---|---|
| Maximum power | 3 500 kW |
| Furnace frequency | 150 Hz |
| Operating voltage | 1 600 V |
| Furnace power source | 11 kV, 3 phase, 50 Hz |
| Nominal capacity of crucible | 6 400 kg |
| Mass of pour | 4 500 kg |
| Duration of melt | 80 min |
| Duration of pouring plus inspections | 10 min |
| Melt cycle | 90 min |
| Heel size | 20 to 30 % of crucible capacity |
| Pouring temperature | 1 650 °C |
| Furnace operating cycle | 24 h per day. |

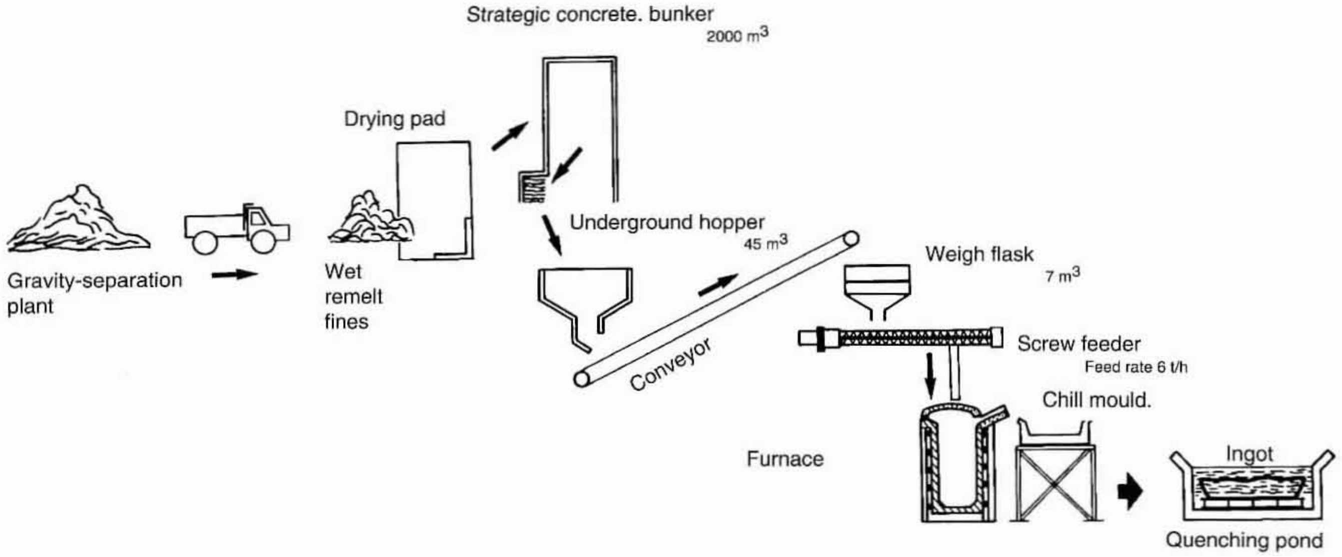


FIGURE 2. Diagrammatic flowsheet for the induction furnace

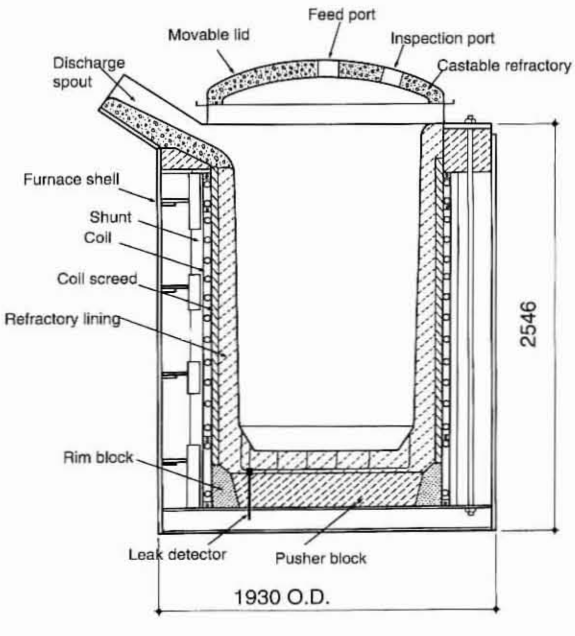


FIGURE 3. Section through the induction furnace

## Refractory Lining – Description and Installation

The furnace is lined with an alumina-magnesia monolithic refractory with the following specifications:

| | |
|---|---|
| $Al_2O_3$ | 84,6% |
| MgO | 14,6% |
| Other | 0,8% (CaO, $Na_2O$, $K_2O$, $SiO_2$, $Fe_2O_3$, and $Cr_2O_3$) |
| Grain size range | 0,1 mm – 5 mm |
| Density (rammed) | 2,85 t/m$^3$ |
| Operating temperature limit | 1 700 °C |

Each lining requires 4 t of refractory material.

The crucible coil is first covered on the inside with a layer of refractory plaster (coil screed) 5 mm thick. The coil screed is then dried using either furnace power or an external heat source placed in the crucible. The dried coil screed is then lined with a 2,2 mm thick flexible filamic Micanite paper. A base block cast from magnesite–alumina based refractory materials forms the bottom of the

## Cooling-water System

The following three cooling-water systems are associated with the induction furnace:

(i) an open circuit that draws water from an existing arc-furnace evaporative-cooling water system
(ii) a closed circuit filled with deionized water
(iii) municipal water.

In the event that the internal cooling circuit cannot be run on deionized water, e.g. during a complete pump failure or breakdown of the standby alternator, municipal water is introduced into this circuit. Water circulation in the circuit will then be driven by the pressure of the municipal water. Figure 4 shows the cooling-water circuits.

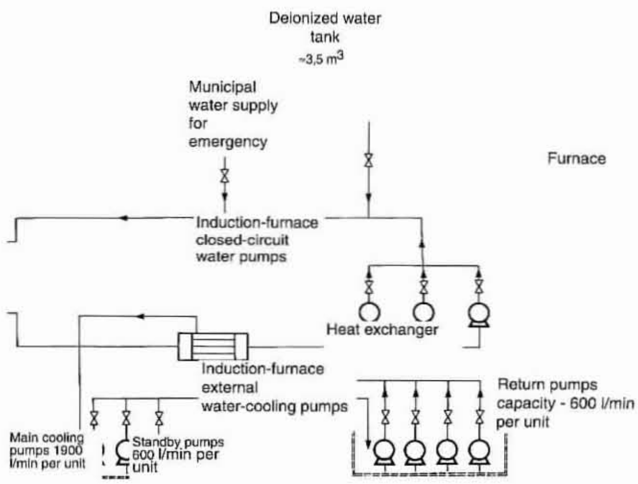


FIGURE 4. Cooling-water circuits

furnace. This block is used as a pusher block to remove the spent lining at the end of each campaign.

The installation of the lining starts with a 150 mm layer of lining refractory material over the pusher block. A cylindrical steel former is placed centrally on the bottom refractory layer and secured in that position by wooden blocks jammed between the former and the coil screed. The annulus between the former and the coil screed is filled with refractory material in layers, each layer being about 150 mm deep. Each layer is compacted with an immersion vibrator, and the top surface is roughened with spikes before the next layer is added. The filling and compaction continue until the annulus is filled.

During the lining process, the prevention of grain-size segregation and contamination of the refractory lining material during handling are critical. Size segregation leads to shorter lining life. To avoid segregation, the refractory material, which is delivered in 25 kg bags, is mixed thoroughly before use. Ten bags at a time are emptied into a clean steel tray and are mixed using shovels. Compaction is carried out according to the manufacturer's specifications.

To guard against contamination of the refractory material, strict hygiene is maintained on the working platform throughout the installation procedure.

## Sintering of the Lining

The two main components in the lining material, MgO and $Al_2O_3$, are present as a mixture in the as-supplied condition. For the refractory material to form an effective insulation layer against the coil, the dry powder has to be sintered at a high temperature to form the spinel ($MgAl_2O_4$).

The procedure currently in use at Zimasco is a result of numerous modifications to the original programme supplied by the refractory-materials manufacturers. The sintering process involves the melting out of the former by means of the following procedure.

Mild-steel scrap is placed in the cold former, which is heated using furnace power. The rate of heating is controlled so that the temperature of the former rises at a rate of 200 °C per hour. The former and the mild-steel scrap start melting at the same temperature, around 1100 °C, and a small steel bath is formed. This serves as the start-up melt. Charging of remelt materials is started once there is a molten-steel bath, and continues till the crucible is full. The bath is further heated to a temperature of 1700 °C and maintained at that level for a period of 1,5 hours to ensure complete fritting of the refractory material. This marks the end of the sintering cycle, which at present takes 12 hours to complete.

## Melting Operations

The induction-melting process is an established classical method of heating metals. It involves four basic steps:

(a) current flow in a coil
(b) inducement of magnetic fields
(c) flow of current in the charge
(d) heating of the charge due to resistance to current flow.

This paper makes no attempt at describing in detail the principles of induction melting but instead, looks at the melting operation as practised by Zimasco.

The melting of the dry fines always starts with a heel. This is necessary because fine material (–1 mm) is not inductive at the frequency and voltage values at which the Zimasco equipment is operated. The size of the heel varies between 20 and 30 per cent of the crucible capacity. Before the addition of feed to the crucible begins, the operator selects a predetermined batch mass on his automatic weigh-feed controller. Although the operator can vary the feed rate, additions are normally steady throughout the heat and average 3,6 t/h. Operational experience has shown that excessive temperatures of the molten bath below the 'bridge' can cause lining erosion and a metal breakthrough, which can result in damage to the coil. Too much feed can result in bridge formation on the melt surface. Too little feed can result in overheating of the already molten material (superheating). The operator therefore tries at all times to match the feed rate and the power-setting on the control panel. The operator also regularly checks the physical condition of the melt.

An immersion thermocouple is used to measure the temperature of the melt towards the end of each heat. Arrangements are being made to install an overhead optical pyrometer that will monitor the surface temperature continuously. The final temperature of the melt is currently set at 1650 °C maximum. Before the final melt is poured into a cast-steel mould, a sample of the slag is taken for chemical analysis. After pouring, two metal samples are taken from either side of the full mould for chemical analysis. This process is repeated on every heat.

## Process Control[1]

The furnace is controlled from a panel in the control room on the charge floor. The following controls are available.

### Power Control

A large-diameter control dial is used to set the desired power to the furnace. The circuit design is such that the set power is maintained even as melting conditions in the crucible change. A countdown kilowatt-meter indicates the progressive power-input summation, and can also be used to run to a set power input. Furnace selector switches are fitted to enable the two furnaces to be used alternately.

### Feed Control

Feed to the furnace is controlled automatically by a computer. The amount to be fed for each heat is preset, and the system will deliver the desired amount each time. The feed rate is controlled from a feed-control console situated next to the furnace. The operator adjusts the feed rate to suit the rate of melting in the furnace, which in turn depends on the power setting.

### Voltage Frequency Monitors

Furnace voltage and frequency are read off from direct-reading dials on the panel.

### Ground/Molten Leak Detector

The ground-leak system continuously monitors earth leakage across the furnace lining. The system will indicate, and shut off the power when metal penetrates the furnace lining to the induction coil, when excessive moisture is present in the furnace lining, or when a low ground resistance exists in the electrical system.

### Melt-temperature Control

The temperature of the melt is taken at regular intervals during the melt cycle using immersion thermocouples. The measured temperature is displayed automatically on a digital panel mounted on the control-room wall.

## Metallurgical and Operating Performance

The induction-furnace melting operations have several advantages compared with Zimasco's other three-phase submerged-arc processes.

The raw materials employed in the process, including the refractory lining material, are cheaper, resulting in a lower production cost.

Fewer process variables are encountered. The chromium recovery in the induction furnace is about 8 per cent higher than in the submerged-arc process (approximately 80 per cent). This factor represents another cost advantage.

When the chromium recovery and power requirements are compared with those of submerged-arc operation, it must be remembered and emphasized that this is a melting operation, not a chromite-smelting operation that involves reduction reactions. The feed-to-product ratio is 1,2, and this depends largely on the slag contained in the feed material. Operational experience has shown that the life of the refractory lining is also influenced strongly by the slag in the feed material, with lower values resulting in better lining performance. The fines fed to the furnace currently contain between 10 and 20 per cent slag.

The operation of the induction furnace results in thorough mixing of the continuously fed charge and the molten bath. The swirling of the molten alloy further results in the promotion of oxidation reactions with atmospheric oxygen. Some of the proposed simplified reactions are as follows:

$$4\ Cr\ (alloy) + 3\ O_2 = 2\ Cr_2O_3 \qquad [1]$$

$$Cr_2O_3 + 3\ C\ (alloy) = 3\ CO\ (g) + 2\ Cr \qquad [2]$$

$$Fe\ (alloy) + 1/2\ O_2 = (FeO) \qquad [3]$$

$$(FeO) + C\ (alloy) = Fe + CO\ (g) \qquad [4]$$

$$(FeO) + CO\ (g) = Fe + CO\ 2\ (g) \qquad [5]$$

$$Si\ (alloy) + O_2 = (SiO_2) \qquad [6]$$

$$SiO_2 + 2C = Si + 2\ CO\ (g) \qquad [7]$$

$$2\ (FeO) + (SiO_2) = 2\ (FeO)\ SiO_2\ (slag). \qquad [8]$$

It is believed that reactions [1] to [8] explain the lower silicon levels in the alloy from the induction furnace compared with the levels associated with the original alloy from submerged-arc furnaces.

Our practice to date is to sample the slag produced after every heat and analyse for total chromium and silica contents. Typical values for the chromium and silica contents are around 5 to 40 per cent respectively. This information is mainly used for statistical comparisons.

Work is in progress on an experimental stage, which is aimed at adjusting the slag regime so as to further reduce the carbon content of the alloy. The experimental procedure involves the addition of certain amounts of chromite ore and quartz to the molten mixture within the crucible of the induction furnace.

The following reactions are thought to influence the decarbonization process:

$$CrO_3 \ + \ 2\ Cr \qquad 3\ CrO \qquad [9]$$

$$Cr^{3+} \ + \ Cr \qquad 3\ Cr^{2+} \qquad [10]$$

$$Cr_2O_3 \ + \ 3\ C \qquad 2\ Cr \ + \ 3\ C. \qquad [11]$$

The carbon monoxide that is formed in reaction [11] distorts the crystal lattice of $Cr_2O_3$ and facilitates the removal of oxygen atoms from the chromite ore. Reaction [10] proceeds much more actively than that of $Cr_2O_3$ because a 2-electron exchange is easier than one involving 3 electrons. It follows therefore that reaction [9] acts as a catalyst for reaction [11], which forms the basis of the decarbonization of ferrochromium.

Table I gives a comparison of the feed and the resultant alloy and slag from the induction-furnace process and the submerged-arc furnaces.

The average number of heats per refractory campaign currently stands at 70.

TABLE I

CHEMICAL ANALYSES OF THE FEED AND THE RESULTANT ALLOY AND SLAG FROM THE INDUCTION-FURNACE PROCESS AND SUBMERGED-ARC FURNACE PROCESS

| Constituent | Induction furnace % | Submerged-arc furnace, % |
|---|---|---|
| **Remelt feed** | | |
| Cr | 56,00 | |
| Fe | 20,00 | |
| C | 5,40 | |
| S | 0,042 | N/A |
| P | 0,022 | |
| Mn | 0,22 | |
| Total silicon | 7,00 | |
| Contained slag | 15,00 | |
| **Slag** | | |
| Cr | 5,23 | 6,63 |
| $SiO_2$ | 40,83 | 28,65 |
| CaO | 2,71 | 3,30 |
| MgO | 26,60 | 29,79 |
| $Al_2O_3$ | 24,81 | 25,59 |
| **Alloy** | | |
| Cr | 66,29 | 66,62 |
| Fe | 25,18 | 24,12 |
| Si | 0,92 | 1,46 |
| C | 7,05 | 6,94 |
| S | 0,044 | 0,05 |
| P | 0,013 | 0,012 |
| Mn | 0,22 | 0,22 |

The production of alloy in 1990 was very close to the design target. Had it not been for teething problems with electrical earth leakage during the last quarter of 1990, the actual production would have surpassed the target by a wide margin. Figure 5 shows the monthly production of gross alloy from commissioning to December 1990. The energy requirements for the induction process are much lower than those for the submerged-arc furnace. The specific power consumption per ton of saleable alloy produced in the induction furnace is about 27 per cent of the value for the submerged-arc process.

Furnace availability has generally been lower than that of the submerged-arc furnaces. Downtime has been due primarily to earth-leakage faults, burst flexible power hoses, and auxiliary-power failure.

Figure 6 shows the availability of the induction furnace for the period May 1989 to December 1990.

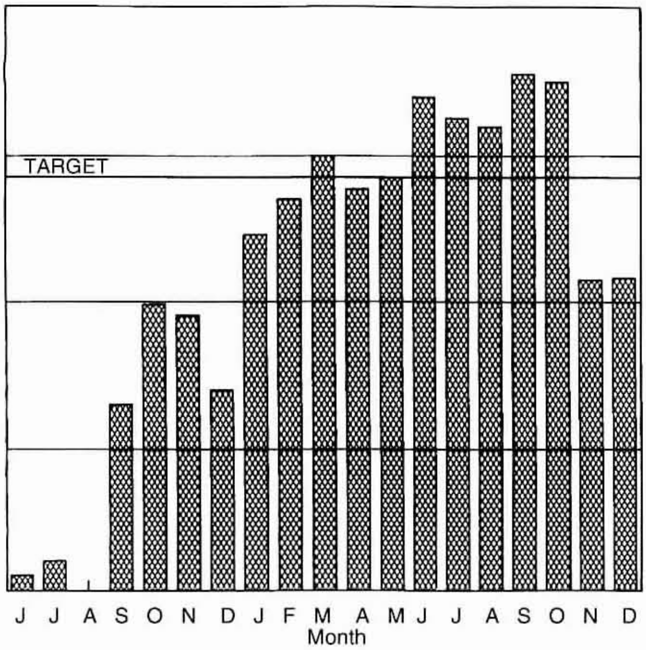


FIGURE 5. Monthly production of gross alloy since commissioning (June 1989 to December 1990)

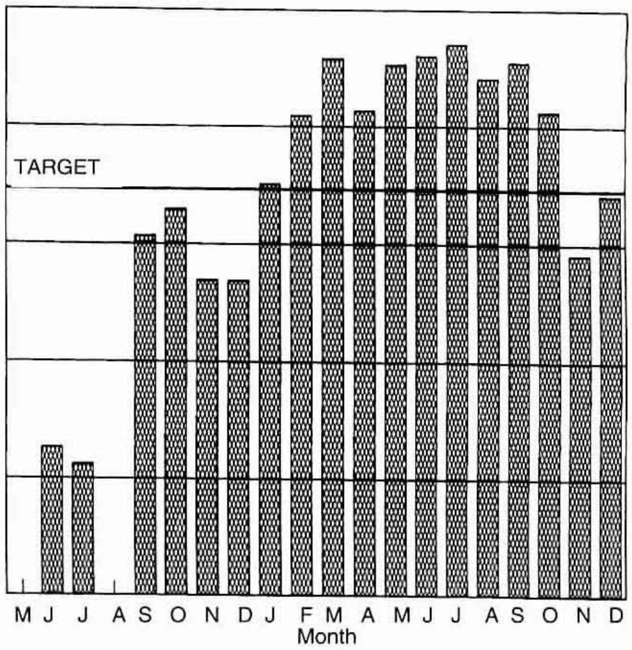


FIGURE 6. Availability of the induction furnace (May 1989 to December 1990)

## Lessons since Commissioning

(1) A combination of mild steel and pig iron has been used as the initial sinter material. As the cold-charge sinter method employed involved the melting out of a mild-steel former, high-carbon ferrochromium could not be used because of its higher melting temperature.

(2) Analysis of refractory-lining wear indicated that the greatest erosion of refractory material occurred in the lower sections of the crucible. This subsequently led to the introduction of a bottom-tapered former designed to increase the thickness of the refractory material in the susceptible areas.

(3) To minimize the accelerated rates of lining wear caused by excessive stirring action, power-setting limits have been introduced for low bath levels.

(4) The early dip-thermocouples had moisture-absorbing refractory sheaths, which caused spark emissions during temperature measurements. These thermocouples will be replaced by ones without the refractory sheath to prevent splashing.

(5) Engineers have managed to overcome power-supply problems by redistributing units connected to the stand-by power equipment. Proper insulation of the inductive coil is vital if earth-leakage faults are to be avoided. Rapid and innovative quick methods of replacing burst power-leads hoses have also been developed.

(6) The continuous monitoring of voltage and frequency reading at a constant bath level has enabled the operators to forecast when failure of the refractory lining can be expected.

(7) Sinter material will be poured into ingot moulds for re-use on subsequent campaigns. This will result in better packing density during the all-important sintering process.

(8) Visual indicators showing system conditions are fitted on the panel and these indicate faults in the capacitor, over-voltage, internal cooling-water system, external cooling-water system, and furnace selector switches.

## Conclusions

Inductive power has been applied to the melting of high-carbon ferrochromium fines at Zimasco. Unit operations have been largely successful, with the output exceeding the targets. Future work will focus on improving product quality and reducing the cost of production. As regards product quality, new methods of casting the alloy separately from the slag will be examined. Investigations will also be carried out on the possibility of reducing the carbon content in the alloy *in situ*.

Cost analysis indicates that refractory-lining materials contribute significantly to the total variable costs of each campaign. Attention is being paid to increasing the number of heats obtained from each campaign by extending the life of the refractory lining.

The future will also be devoted to optimizing the melting operation by automatic linkage of key process-control parameters, e.g. actual power input and mass feed rates.

## Acknowledgments

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## Reference

1. Inductotherm Corp., Rancocas, NJ 08073, USA. (1984). *Power Trak and Power Melt systems manual – operating procedures and maintenance instructions.*