FASTMET®: Proven Process for Steel Mill Waste Recovery

James M. McClelland, Jr. P.E.
Manager-Technical Sales
Midrex Technologies, Incorporated
2725 Water Ridge Parkway
Charlotte, North Carolina, 28217
USA
Tel: 704-378-3359
FAX: 704-373-1611
E-mail: jmcclelland@midrex.com

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Abstract:

Two FASTMET™ Process steel mill waste recovery plants are now in commercial operation. These FASTMET™ Process facilities are converting steel mill wastes into useable iron units and valuable by-products. This paper discusses operating experience from both plants; including waste oil fuel operation, product quality, zinc recovery and emissions testing.
INTRODUCTION

Midrex Technologies, Inc. in partnership with its parent company, Kobe Steel, Ltd. has developed the FASTMET Process as a solid carbon based reduction technology; applicable for processing iron ore as well as iron oxide containing materials such as steel mill wastes. Addition of an Electric Iron Melting Furnace (EIF®) to the FASTMET Process has resulted in the FASTMELT® Process, an economical solution for production of high quality hot metal.

Most steelmakers are searching for appropriate ways to recycle steel making wastes including BF and BOF dusts and sludges, mill scale, and EAF dust. Accumulations of EAF steel making dust and its disposal have become a concern worldwide. There are two aspects in EAF dust recycling; one is to recycle valuable resources, iron bearing materials to steel making and crude zinc oxide to non-ferrous metals recovery and another is to reduce environmental pollution. From both economical and environmental points of view, FASTMET Process is very attractive as a proven technology for EAF dust recycling.

As for dust recycling to BOF/EAF feed, there are two major targets of the process. One is the higher metallization of iron oxides, which would reduce the burden on the melting process. Another is high removal ratio of zinc, which would reduce concentration of zinc within the recycling loop. For BF feed, high compression strength is required, which was also achieved by adjusting binder and mixing ratio of raw materials with the FASTMET Process.

The FASTMET Process has been proven to achieve both high metallization and high zinc removal ratio in dust recycling process through laboratory tests and tests at Kakogawa Demonstration Plant. These tests resulted in the design concept of the first commercial FASTMET Plant. The first commercial FASTMET Plant was constructed, commissioned and turned over to the client for commercial operation at Nippon Steel’s Hirohata Works. The second commercial FASTMET Plant is now in operation at Kobe Steel’s Kakogawa Works.

This paper presents information and data collected during the startup and initial operation of these first commercial FASTMET Plants.

STEELMAKING WASTES & ASSOCIATED PROBLEMS

Many operating steel mills today are concerned about the handling of wastes. These concerns compound yearly, and steelmakers need be more proactive towards finding solutions. Some of these problems are:

- Disposal of iron-bearing wastes – Non-hazardous wastes from integrated mills represent a loss of valuable iron and carbon unit. Landfill or dumping of these wastes is an additional cost. Electric furnace baghouse dust, which is listed as a hazardous material (KO61) by the U.S. EPA, can be a serious environmental threat if simply dumped. Proper thermal processing or stabilization before landfilling is expensive and wasteful of valuable resources.

- Closure of on-site landfills – Steel mills world wide have stockpiled wastes on site for years, some even decades. Theoretically, because the land is “free,” this is a low-cost approach. However, many of these on-site landfills are filling up and coming under increased scrutiny by environmental authorities.

- Recovery of valuable iron units – Integrated mills pay $40-45/tonne for iron oxide pellets. With a typical iron content of 65%, this translates to a metallic iron cost of $60-70/tonne. The mill is literally throwing money away if the pellet fines are not recycled. In the case where mini or integrated mills are using DRI as feed, the economic effect of not recycling DRI fines can be threefold that of oxide pellets.
• Controlling steelmaking raw material costs – Successful steel mills must continually reduce costs. One effective way to do this is by processing waste materials and thereby eliminate the associated landfill fee.

• Conservation of capital – Most steelmakers have restricted the amount spent on the hot end of their operations, opting instead to focus investment on the more profitable downstream side. An on-site waste processing plant that is possibly built, owned, and operated by a third party allows steelmakers to conserve capital funds and avoid the responsibility of another hot end operation.

• Environmental problems of coke ovens and sinter plants – Stricter EPA regulations on integrated mill emissions, especially from coke ovens, are a major problem. Many companies would shut down sinter plants and coke ovens if there was a viable alternative.

THE ANSWER TO DEALING WITH WASTES

Over the past 10 years, Midrex and Kobe Steel have been developing the FASTMET process that will enable the steelmaker to deal with steel mill waste problems. The FASTMET Process converts steel mill wastes, with or without the addition of iron ore fines, into metallized iron in a rotary hearth furnace (RHF) using carbon as the reductant. The product can be cold DRI, hot DRI, HBI, or hot metal; depending on end use requirements.

FASTMET PROCESS BACKGROUND

The rotary hearth furnace was first applied to direct reduction of iron in the 1960s by Midland Ross Corporation, a forerunner of MIDREX, and was known as “Heat Fast”. The Heat Fast Process consisted of mixing and pelletizing iron oxide concentrate and pulverized coal, drying the pellets on a grate, pre-reducing the pellets on a rotary hearth, and then cooling the pellets in a shaft cooler.

The Heat Fast Process was tested successfully at a 2 ton/h pilot plant in Cooley, Minnesota, from 1965 to 1966. Simultaneous to the development of Heat Fast, the natural gas-based MIDREX® Direct Reduction Process, which offered a higher quality product than Heat Fast and lower operating costs (natural gas was priced at about one tenth of today’s price) was also being developed. Due to the then low operating costs of the natural gas process, the Heat Fast process work was halted and commercial development was never undertaken.

MIDREX revived its interest in using the RHF for direct reduction in the early 1980s. Several studies were conducted which indicated that an RHF-based process could be developed to produce direct reduced iron at an attractive price based on U.S. conditions. Still, however, the economics of the gas-based process were more attractive and the gas-based process well proven. Again, coal-based reduction was put behind the now “traditional” gas process.

In the 1990’s, the books were reopened and additional studies were conducted that affirmed that the economics for a RHF coal-based process were attractive. At this point, a decision was made to proceed with the process development with the intent of commercializing the technology. Building upon the Heat Fast pilot plant work dating back to the 1960s, improvements were made to the technology which resulted in higher productivity, improved product quality, greater process flexibility, and increased process efficiency. The end result was the development of the FASTMET Process.
MIDREX and KSL have taken the FASTMET Process one step further in developing the FASTMELT® Process. This entails the hot discharge of DRI from the RHF and charging by gravity into an Electric Iron Furnace (EIF™), a melting furnace specifically designed for melting FASTMET hot DRI to produce hot metal. This hot metal is known as FASTIRON®.

**History of FASTMET® Process Development**

- **1960s** Midland Ross (MIDREX = MIDland Ross EXPERimental) developed HEAT FAST Process; 2 t/h pilot plant built in Cooley Minnesota and operated from 1965 to 1966.
- **1990** MIDREX began development work on FASTMET® Process.
- **1992** FASTMET pilot plant built at Midrex Technical Center; 2.75 m RHF, 160 kg/h; > 100 campaigns run from 1992 to 1994.
- **1995** Kakogawa Demonstration Plant built at KSL’s Kakogawa Steel Works; 8.5 m RHF, 2.5 tph; continuous development operation from 1995 to 1998.
- **1998** Electric Ironmaking Furnace (EIF®) installed at Midrex Technical Center; direct coupled to the FASTMET Pilot Plant RHF; 150 kg/h hot metal; successfully demonstrated FASTMELT® Process to produce blast furnace grade hot metal from virgin iron oxides and steel mill wastes.
- **2000** First Commercial FASTMET Plant (FDPR) at Nippon Steel’s Hirohata Works; 21.5 m RHF; 192,000 tpy BOF Sludge and Dust Treatment; Products are 140,000 tpy Hot DRI and 2,250 tpy Crude Zinc Oxide.
  - March 21, 2000 1st Product
  - April, 2000 Continuous Operation
  - July, 2000 Performance Guarantee Test Completed, Operation turned over to Nippon Steel.
  - July, 2001 One year of continuous operation; typical DRI metallization 91.9%, zinc recovery 94%, Hot DRI delivery temperature > 1000° C, 1st year Availability > 90%.
  - August, 2002 Feed briquetting system commissioned.
- **2001** Second Commercial FASTMET Plant (KDTP) at KSL’s Kakogawa Works; 8.5 m RHF; 14,000 tpy BOF Dust, EAF Dust and Mill Waste Treatment; Waste Oil fuel; Products are 11,000 tpy DRI and 1,400 tpy Crude Zinc Oxide.
  - May, 2001 Plant Startup

**FASTMET PROCESS DESCRIPTION**

The FASTMET Process converts iron oxide pellet feed, oxide fines and / or steel mill wastes into metallic iron using, when necessary, pulverized coal or other carbon-bearing material as a reductant. The end product, direct reduced iron, can be hot briquetted, discharged as hot DRI into transfer containers, cooled if cold DRI is required, or directly charged to a melter (EIF) for production of Hot Metal or Pig Iron.

Refer to Figure 2 for FASTMET/FASTMELT Process Flowsheet.
In operations where the primary feed is virgin ore, concentrates and ground reductants are pelletized and dried before being sent to the RHF. Here the materials are fed to the furnace in a single layer. In cases in which steel mill wastes are the primary feed materials, the wastes can be briquetted. Briquetting provides more flexibility in utilizing the waste materials, reduces much of the need for grinding feed materials and eliminates the necessity of drying the green compacts. The briquettes are also placed on the hearth in a single layer (see Fig. 3).
As the hearth rotates, the briquettes are heated by radiation from RHF zone temperatures of more than 1300°C, and the iron oxide is reduced to metallic iron. Reduction of the iron oxide is accomplished primarily by fixed elemental carbon (C) reacting with magnetite (Fe$_3$O$_4$) or hematite (Fe$_2$O$_3$) to form metallic iron (Fe$^\circ$) and wustite (Fe$_{0.95}$O) in the solid form while evolving carbon monoxide (CO) and carbon dioxide (CO$_2$) gas. Some of the carbon goes into solid solution with the metallic iron to form iron carbide (Fe$_3$C).

Zinc Oxide, Lead Oxide, and other volatile metallic oxides contained in steel mill waste feed are also reduced to metallic form and vaporized. These metallic vapors are reoxidized in the flue gas before exiting the furnace through the Off Take.

Residence time on the hearth is typically 6 - 10 minutes. This varies depending on the material being processed, size of briquettes, and other factors. During this time, 85 - 95 percent of the iron oxide is converted to metallic iron. The rapid reduction rate achieved in the FASTMET Process is attributed to the high reduction temperature, the high heat transfer rate, and the intimate contact of the carbon contained inside the briquettes with the iron oxide.

The flue gas leaving the RHF is fully combusted, containing approximately 2% oxygen. Heat exchangers use the thermal energy in the flue gas to preheat combustion air for the RHF burners and raw material preparation dryer.

Flue gas leaves the rotary hearth furnace through the roof and flows through a refractory lined offtake to the flue gas duct. Proper location of the flue gas offtake relative to the RHF combustion zones is determined by analysis of the feed materials, reduction kinetics, and verified by Computational Fluid Dynamics. Dilution air is injected into the flue gas duct to provide cooling and burn any remaining combustibles (H$_2$ and CO) in the flue gas stream.

Spray water is added to the primary cooler to cool the gas from > 1400°C to 1000°C to minimize NO$_x$ formation and provide an acceptable inlet temperature for the recuperator.

From the primary cooler flue gas flows through the combustion air and dryer air preheater where the heat from the flue gas is used to heat combustion air for the rotary hearth burners and rotary dryer.

The flue gas exits the combustion air preheater to the secondary cooler. Spray water is added to the secondary cooler to cool the gas from approximately 800°C to 120°C to provide an acceptable inlet temperature for the bag filter system.

The flue gas then flows to a pulse jet fabric filter baghouse where the crude zinc oxide is collected and then to an I.D. fan where it is discharged through a stack to the atmosphere.

SO$_2$ control is not normally required for FASTMET Plants processing steel mill waste materials as most of the SO$_2$ reacts with and is absorbed by the metallic oxides in the flue gas stream. Lime injection may be used to further control SO$_2$. NO$_x$ is controlled by use of low NO$_x$ burners and close operational control of air to fuel ratio and combustion temperatures. Dioxins and Furans are destroyed by the high temperature and long residence time within the RHF. Flue gas cooling rate is controlled to minimize Dioxin and Furan reformation. Particulates are removed from the flue gas by a bag filter system. Crude zinc oxide will be collected by the bag filter system and stored in a silo. Crude zinc oxide will be transferred from the silo to the buyer’s truck or rail car.
The metallization (percent of total iron in metallic form) of the direct reduced briquettes can be adjusted. Carbon content of the briquettes can be adjusted to obtain target DRI carbon content. Product chemistry will vary depending upon the chemistry of the oxide, the reductant, and the binder used.

THE EAF WASTE TREATMENT OPTION

FASTMET leaves the mini-mill steelmaker with another option to handling the dust over the current high treatment costs. A FASTMET Plant located at the steelmaking site can process the dust and make two primary products, DRI for feed back to the melter, and crude zinc oxide for sale to zinc processors. What was a liability now becomes an asset. The high cost of disposal is eliminated and an inexpensive supply of iron units becomes available. To summarize the benefits:

- Very low fines generation in the process results in high zinc content and very low iron content of the secondary dust.
- High metallization and high zinc removal make reduced iron product recyclable to the EAF.
- No waste is generated for disposal.
- High temperature treatment decomposes dioxins.
- Zinc dust can be treated economically and becomes a product, not a waste.

Table I shows the results of a laboratory simulation test of typical EAF dust treatment by FASTMET. The case (EAF dust + coal) represents EAF dust processing using coal as reducing agent.

**Table I: EAF Dust Treatment, Unit : Weight %**

<table>
<thead>
<tr>
<th>EAF dust + Coal</th>
<th>T.Fe</th>
<th>M.Fe</th>
<th>C</th>
<th>ZnO</th>
<th>PbO</th>
</tr>
</thead>
<tbody>
<tr>
<td>EAF dust</td>
<td>32.23</td>
<td>0.02</td>
<td>1.70</td>
<td>24.20</td>
<td>4.10</td>
</tr>
<tr>
<td>Coal</td>
<td>0.45</td>
<td>0.00</td>
<td>74.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>DRI</td>
<td>58.09</td>
<td>52.28</td>
<td>2.02</td>
<td>2.18</td>
<td>0.00</td>
</tr>
<tr>
<td>By-product</td>
<td>0.05</td>
<td>0.04</td>
<td>0.00</td>
<td>74.33</td>
<td>13.26</td>
</tr>
</tbody>
</table>

**RAW MATERIALS SUITABLE FOR PROCESSING**

The raw materials for the process can be classified into three categories: iron oxides (i.e. virgin materials or iron bearing materials), reductants (i.e. carbon source), and a binder. An extensive group of raw material combinations (i.e. iron bearing waste materials and different reductants) have been evaluated in laboratory scale testing, pilot plant work and/or test work at Kakogawa. A partial list of evaluated raw materials is given below:

- Blast Furnace Filter Cake
- BOF Filter Cake
- Mill Scale
- EAF Baghouse Dust
Pellet Fines
• Iron Ore Concentrates
• Indian Blue Dust
• Blast Furnace Dust and Sludge
• Coke Breeze
• Low/Medium/High Volatile Coals
• Pet Coke
• Charcoal

If blast furnace dust or sludge is used, there may be sufficient carbon in the feed to accomplish reduction without additional reductant.

FASTMET / FASTMELT can enhance the waste materials being processed and recover valuable iron units. FASTMET, if DRI or HBI is selected as the final product, the process can only convert the iron present in the materials that make up the RHF feed. The product will retain amounts of gangue in direct proportion to the materials being processed. If FASTIRON is the desired product, and the material noted above is fed to the FASTMELT Melter, then the gangue will come off in the slag. The gangue effect can be moderated by the addition of virgin ore that has a high Fe content. This is a reaction that will occur in any process where wastes are treated.

**FIRST COMMERCIAL FASTMET PLANT**

In April of 2000, the first commercial FASTMET plant was commissioned at Nippon Steel Hirohata Works in Japan. The plant recycles 190,000 tonnes per year of steel mill dust, which is a combination of BOF dust and BOF filter cake generated at Hirohata Works. The Hirohata FASTMET plant produces approximately 18 tonnes per hour of hot direct reduced iron with a metallization of 90%. DRI Product discharge temperature is >1000° C.

The Hirohata FASTMET plant receives as generated wastes directly from the steel works. These mill wastes are combined with coal and binder then mixed and briquetted. The briquettes are screened and dried to a moisture content of less than 0.5 percent.

The dried briquettes are continuously fed to the RHF. The RHF has a diameter of approximately 21.5 meters with an effective hearth width of 3.75 meters. There are six burner/reaction zones. All of the burners are fueled by LNG. After 8 to 10 minutes of heating the DRI passes under a chill plate and is removed from the hearth surface by means of a water-cooled discharge screw. The hot DRI product is collected in transfer containers and transported by means of a carrier truck to the BOF shop for charging.

Zinc oxide removal rate is more than 94%. More than 300 kg/hr of dust is collected from the off gas system with a zinc content of 60 to 65%. This dust is sold in Japan for approximately 1/3 of LME metallic zinc price.

Hot off gas exiting the RHF is cooled by means of an evaporative cooler before it enters a heat exchanger. Sensible heat in the off gas is used to preheat the RHF combustion air and the greenball dryer air to about 350° C. The off gas exiting the preheater is further cooled by a second evaporative cooler before entering a baghouse, where the zinc oxide is recovered and sent to the dust silo for storage. An induced draft fan is positioned on the baghouse outlet to achieve the required pressure drop for the flue gas system and control the RHF under a slightly negative pressure.
Utilities such as LNG, plant air, nitrogen, steam, instrument air, and make-up water are supplied to the battery limit by Nippon Steel. The plant includes an open recirculating process water circuit as well as closed machinery cooling water circuit.

The Hirohata FASTMET Plant successfully completed a plant performance guarantee test on August 3, 2000 and has been operating consistently with a product metallization of 90%. The plant achieved a hearth productivity of 100 kg/m²/h during the performance and operating period.

The second commercial FASTMET Plant began operation in April 2001 at the Kakogawa Works of Kobe Steel, Ltd. in Japan. This is part of Kobe’s plan to turn Kakogawa into a zero emissions facility by the end of 2001, an industry first.

Building on the success of the first commercial FASTMET Recycling Plant at Nippon Steel’s Hirohata Works in Japan, Kobe Steel, Ltd. converted the FASTMET Demonstration Plant at its Kakogawa Works into an iron-bearing solid waste recycling facility. Using waste oil as the primary fuel source, the demonstration plant has been modified to process blast furnace and steelmaking dust, including upgrading the offgas-cleaning unit to recover high zinc content dust.

The Kakogawa FASTMET Plant reclaims zinc-rich iron oxide dust from blast furnace and steelmaking operations, with a treatment capacity of 16,000 metric tons per year. The facility uses pellets made of blast furnace and steelmaking dust that are then fed to a rotary hearth furnace and heated to a high temperature. The carbon in the waste acts as a reductant and reacts with the oxygen in the iron oxide in a relatively short time, producing highly metallized DRI. The DRI is used in steelmaking operations.

**COMMERCIAL PLANT RESULT**

Through the demonstration plant tests at KDP, FASTMET Process proved that it could reduce iron oxide contained in the steel dust at very high metallization, and at the same time it could remove zinc oxide contained in the steel dust at very high dezincification degree. These benefits were proven at the commercial FASTMET Plant, which is designed based on the laboratory tests and demonstration plant tests.

The first commercial FASTMET Plant started continuous operation from April 2000. Because of the extensive test work done the commercial plant start up was smooth and proceeded rapidly to design conditions. The Performance Guarantee Test was completed in July, 2000 and the plant was turned over to the client for normal commercial operation. Fig. 7 shows process flow of the first commercial FASTMET Plant.

**Fig. 7 FASTMET Commercial Plant Process Flow**
Fig. 8 shows the average hourly steel dust treatment rate curve.

![Dust Treatment Rate](image)

**Fig. 8 Dust Treatment Rate**

Fig. 9 shows an overview of the monthly waste treatment

![Monthly Average Waste Treatment](image)

**Monthly Average Waste Treatment**
Fig. 10 shows the availability of the plant during continuous operation period.

Typical metallization degree at commercial FASTMET plant is 91.9% and dezincification degree is 94.0% at high hearth productivity of 100 kg-DRI/m²h. Table 5 shows typical Green Pellet analysis and resulting DRI analysis.

Flue gas dust contains very high zinc oxide concentration. Typically the collected dust zinc content is 63.4%, 78.9% as zinc oxide. Iron content of the collected dust is typically less than 1%. Thus, flue gas dust from FASTMET plant is highly valued as a zinc resource.

<table>
<thead>
<tr>
<th>Dry Ball</th>
<th>DRI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Iron</td>
<td>58.1%</td>
</tr>
<tr>
<td>Metallic Iron</td>
<td>21.3%</td>
</tr>
<tr>
<td>Carbon</td>
<td>11.6%</td>
</tr>
<tr>
<td>Zinc</td>
<td>1.0%</td>
</tr>
<tr>
<td>Metallization</td>
<td>91.9%</td>
</tr>
<tr>
<td>Dezinc</td>
<td>94%</td>
</tr>
</tbody>
</table>

Table 5 Typical Green Pellet & DRI analysis

In addition to the above profits, the first commercial FASTMET plant also shows that FASTMET process is environmentally friendly. The emission limitations for all pollutant are satisfied including dioxin limitation.

Typical emission data as measured from the commercial plant is shown in Table 6.

<table>
<thead>
<tr>
<th></th>
<th>NOx (Nm³/h)</th>
<th>SOx (Nm³/h)</th>
<th>Dust (kg/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Guarantee</td>
<td>&lt;3.8</td>
<td>&lt;2.7</td>
<td>&lt;2.09</td>
</tr>
<tr>
<td>Actual</td>
<td>1.98</td>
<td>0.08</td>
<td>&lt;0.12</td>
</tr>
</tbody>
</table>

Dioxin < 0.1 ng – TEQ/Nm³

Table 6 Emission data of FASTMET commercial plant
SECOND COMMERCIAL FASTMET PLANT

The second commercial FASTMET Plant is now in operation at Kobe Steel’s Kakogawa Steel Works. This plant is the former FASTMET Process Demonstration Plant (KDP). KDP has been modified for continuous operation, processing zinc rich waste oxides and blast furnace dust. Plant startup was in May 2001. Refer to Fig. 11 for process information.

![Kakogawa FASTMET Plant Process Description](image-url)

**Fig. 11.** Kakogawa FASTMET Plant Process Description.
The following tables show examples of feed mix chemistry, DRI product and Flue gas dust from the Kakogawa FASTMET Plant.

Table 7. Waste Chemical Composition (Example)

<table>
<thead>
<tr>
<th></th>
<th>C</th>
<th>T. Fe</th>
<th>Zn</th>
<th>Na2O</th>
<th>K2O</th>
<th>S</th>
<th>Mn</th>
<th>CaO</th>
<th>SiO2</th>
<th>Al2O3</th>
<th>MgO</th>
<th>Cl</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>BF Filter Cake</td>
<td>37.6</td>
<td>31.8</td>
<td>1.2</td>
<td>0.2</td>
<td>0.6</td>
<td>0.7</td>
<td>-</td>
<td>3.1</td>
<td>4.1</td>
<td>-</td>
<td>-</td>
<td>0.065</td>
<td>0.16</td>
</tr>
<tr>
<td>EAF Dust</td>
<td>0.22</td>
<td>31.25</td>
<td>21.1</td>
<td>1.45</td>
<td>1.35</td>
<td>0.17</td>
<td>3.33</td>
<td>10.34</td>
<td>6.18</td>
<td>0.85</td>
<td>3.516</td>
<td>0.29</td>
<td>4.84</td>
</tr>
<tr>
<td>BOF Flue Dust</td>
<td>0.70</td>
<td>53.6</td>
<td>2.54</td>
<td>1.011</td>
<td>5.818</td>
<td>0.1</td>
<td>0.31</td>
<td>5.0</td>
<td>0.76</td>
<td>0.315</td>
<td>0.185</td>
<td>3.3</td>
<td>0.96</td>
</tr>
</tbody>
</table>

Table 8. DRI Chemical Composition (Example)

<table>
<thead>
<tr>
<th></th>
<th>T. Fe</th>
<th>M. Fe</th>
<th>FeO</th>
<th>C</th>
<th>S</th>
<th>Mn</th>
<th>CaO</th>
<th>SiO2</th>
</tr>
</thead>
<tbody>
<tr>
<td>68.0</td>
<td>57.8</td>
<td>13.3</td>
<td>2.00</td>
<td>0.52</td>
<td>1.07</td>
<td>4.35</td>
<td>5.95</td>
<td></td>
</tr>
</tbody>
</table>

Table 9. Flue Gas Dust Chemical Composition (Example)

<table>
<thead>
<tr>
<th>Zn</th>
<th>Pb</th>
<th>T.Fe</th>
<th>Na</th>
<th>K</th>
<th>S</th>
<th>Cl</th>
<th>F</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>56.4</td>
<td>4.99</td>
<td>0.32</td>
<td>3.13</td>
<td>10.79</td>
<td>1.69</td>
<td>4.86</td>
<td>0.15</td>
<td>0.01</td>
</tr>
</tbody>
</table>

The Kakogawa FASTMET is currently operating on a two shift basis, processing zinc bearing wastes collected from various points within the Kakogawa Steel Works. The RHF burners are being fueled by a mixture of waste oil and coke breeze named Slurmix.

FASTMELT® THE FUTURE OF IRONMAKING

Successful operation of the two commercial FASTMET Plants has proven the viability of the FASTMET Process. FASTMELT® is the next step in this key ironmaking technology. FASTMELT adds a melter to the FASTMET Process to produce blast furnace equivalent hot metal suitable for production of merchant pig iron or direct conversion to steel. The FASTMELT Electric Ironmaking Furnace (EIF®) has been demonstrated at Midrex Technical Center, producing blast furnace chemistry hot metal from steel mill waste oxides. A commercial FASTMELT Plant will produce hot metal using less energy than most other methods, including the blast furnace.
FASTMELT Process Comparison

Following are comparisons of the FASTMELT Process with other ironmaking processes – some well established - others under development.

Energy consumption is most important in today’s era of high energy costs and environmental concerns. Table 10 compares FASTMELT with other iron making processes on an equivalent GJ per tonne of Hot Metal basis. Carbon Dioxide Emissions are also a good indication of overall process efficiency. Table 11 compares FASTMELT with other iron making processes on the basis of tonnes of CO₂ per tonne Hot Metal.

Table 10. Energy Consumption

<table>
<thead>
<tr>
<th>(GJ/tonne Hot Metal)</th>
<th>FASTMELT ¹</th>
<th>Hlsmelt²</th>
<th>COREX³</th>
<th>REDSMELT⁴</th>
<th>Blast Furnace⁵</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>12.25</td>
<td>19.47</td>
<td>30.77</td>
<td>14.85</td>
<td></td>
</tr>
<tr>
<td>Natural Gas</td>
<td>2.68</td>
<td>2.2</td>
<td>0.5</td>
<td>2.17</td>
<td></td>
</tr>
<tr>
<td>Electricity ⁶</td>
<td>6.11</td>
<td>3.38</td>
<td>0.83</td>
<td>6.65</td>
<td></td>
</tr>
<tr>
<td>Subtotal</td>
<td>21.03</td>
<td>25.05</td>
<td>32.10</td>
<td>23.67</td>
<td></td>
</tr>
<tr>
<td>Off Gas Energy Credit</td>
<td>&lt;4.56&gt;</td>
<td>&lt;3.38&gt;</td>
<td>&lt;13.2&gt;</td>
<td>&lt;5.1&gt;</td>
<td>&lt;5.35&gt;</td>
</tr>
<tr>
<td>Total Energy</td>
<td>16.48</td>
<td>21.67</td>
<td>18.9</td>
<td>18.56</td>
<td>18.01</td>
</tr>
</tbody>
</table>

Note that the Coal and Natural Gas consumption for FASTMELT have been demonstrated at the Nippon Steel Hirohata FASTMELT commercial plant.

Table 11. Carbon Dioxide Emissions; tonnes of CO₂/tonne Hot Metal

<table>
<thead>
<tr>
<th></th>
<th>FASTMELT ¹</th>
<th>Hlsmelt²</th>
<th>COREX³</th>
<th>REDSMELT⁴</th>
<th>Blast Furnace⁵</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>1.138</td>
<td>1.809</td>
<td>2.859</td>
<td>1.380</td>
<td>2.170</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>0.153</td>
<td>0.125</td>
<td>0.058</td>
<td>0.124</td>
<td>0</td>
</tr>
<tr>
<td>Electricity ⁴⁵⁶⁷⁸⁹</td>
<td>0.242¹¹</td>
<td>0</td>
<td>0.129</td>
<td>0.242¹²</td>
<td>0</td>
</tr>
<tr>
<td>Subtotal</td>
<td>1.533</td>
<td>1.934</td>
<td>3.046</td>
<td>1.746</td>
<td>2.170</td>
</tr>
<tr>
<td>Less equivalent CO₂ of carbon in Hot Metal</td>
<td>&lt;0.147&gt;¹³</td>
<td>&lt;0.147&gt;</td>
<td>&lt;0.169&gt;¹⁴</td>
<td>&lt;0.132&gt;¹⁵</td>
<td>&lt;0.147&gt;</td>
</tr>
<tr>
<td>Total CO₂ Produced</td>
<td>1.386</td>
<td>1.787</td>
<td>2.877</td>
<td>1.614</td>
<td>2.023</td>
</tr>
</tbody>
</table>

Table 12 (located at the end of this paper) shows a comparison of expected Hot Metal Product analysis form various processes and general Pig Iron specifications for various uses.

¹ Commercial FASTMELT Proposal, September 1999
³ VAI publication, “The COREX® C-3000 Generation”
⁴ Skillings 1999, “Demag’s REDSMELT Process For The Iron Ore Mining Industry”
⁶ Electricity is stated as the energy of coal used to generate power therefore is not a direct conversion of kWh to GJ.
⁷ Coal Conversion = 92.91 Kg CO₂/GJ coal.
⁸ Natural Gas Conversion = 56.96 Kg CO₂/GJ natural gas.
⁹ Assume all Off Gas Energy Credit is used for internal electric power needs.
¹⁰ Electricity Conversion = 155.91 Kg CO₂/GJ electricity
¹¹ 6.11 – 4.56 = 1.55 GJ/tonne hot metal net electrical energy in.
¹² 6.65-5.1=1.55 GJ/tonne hot metal net electrical energy in.
¹³ 4% carbon in hot metal
¹⁴ 4.6% carbon in hot metal
¹⁵ 3.6% carbon in hot metal
Conclusions

FASTMET Process for steel mill waste recovery is well proven through the successful operation of two commercial plants. Valuable mineral resources, previously landfilled, are economically recovered and reused by the FASTMET Process. FASTMET is a good neighbor with minimal environmental impact and can be shown as BACT for EAF dust treatment.

FASTMET, the critical processing steps of the FASTMELT Process have been proven and commercially demonstrated. A comparison of FASTMELT to other established iron making processes shows FASTMELT well suited to economical production of iron. This flexible process efficiently uses a wide variety of iron oxides and carbon sources to produce a high quality hot metal or pig iron product. The processing steps are well defined and easily understood. The Plant safely operates with simple controls at low pressures and reasonable temperatures. The FASTMELT Plant is an assembly of proven, readily available equipment without exotic machinery, expensive alloys or catalysis. The refractories are standard ironmaking specification. The EIF is a rugged design based on proven EAF and Ladle Furnace technologies.

FASTMELT presents an economical solution to ironmaking in module capacities similar to the Mini Blast Furnace ranging from 100,000 to 500,000 tonnes per year of Hot Metal production. (Note: one module is considered one RHF direct coupled to one EIF).

Greenfield site budget costs for FASTMET Plants range from US$ 150 to 200 per annual tonne of DRI product. FASTMELT Plants budget costs range from US$ 250 to 300 per annual tonne of Hot Metal.

Success of the FASTMELT Technology is due years of development by Midrex and Kobe Steel. Each partner brings an attention to detail that comes from years of applied ironmaking technologies and engineering in many related fields such as pelletizing and direct reduction. The operational expertise necessary for a successful commercial project is the result of many Midrex and Kobe Steel man-hours of research, pilot plant and demonstration plant operation, and operating plant experience.
### Table 12 Comparison of expected Hot Metal Product analyses.

<table>
<thead>
<tr>
<th></th>
<th>FASTMELT</th>
<th>Hismelt</th>
<th>COREX</th>
<th>REDSMELT</th>
<th>Blast Furnace</th>
<th>Pig Iron for Oxygen Steelmaking</th>
<th>Pig Iron for Electric Furnace Steelmaking</th>
<th>Foundry Grade Pig Iron</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon (controllable range)</td>
<td>3.0 to 5.0%</td>
<td>3.5 to 4.5%</td>
<td>4.5 to 4.7%</td>
<td>3.6%</td>
<td>4.0 to 4.5%</td>
<td>3.5 to 4.4%</td>
<td>3.5 to 4.5%</td>
<td>3.0 to 4.5%</td>
</tr>
<tr>
<td>Silicon</td>
<td>0.2 to 0.6%</td>
<td>no silicon reduction in process</td>
<td>0.6 to 0.8%</td>
<td>0.2%</td>
<td>0.3 to 1.5%</td>
<td>0.20 to 2.0%</td>
<td>0.5 to 1.5%</td>
<td>0.5 to 3.0%</td>
</tr>
<tr>
<td>Manganese</td>
<td>0.6 to 1.2%</td>
<td>0 to 0.2%</td>
<td>Not reported</td>
<td>0.6%</td>
<td>0.25 to 2.2%</td>
<td>0.4 to 2.5%</td>
<td>1 to 1.25% max.</td>
<td>1.25% max</td>
</tr>
<tr>
<td>Phosphorus (depends on P% in feed)</td>
<td>&lt; 0.05%</td>
<td>0.02 to 0.05%</td>
<td>Not reported</td>
<td>Not reported</td>
<td>0.04 to 0.2%</td>
<td>0.40% max</td>
<td>0.1 to 0.12% max.</td>
<td>0.035% max</td>
</tr>
<tr>
<td>Sulfur</td>
<td>&lt; 0.03%</td>
<td>0.05 to 0.15% (requires desulfurization)</td>
<td>0.01 to 0.03%</td>
<td>0.05</td>
<td>0.03 to 0.8% (may require desulfurization)</td>
<td>0.05% max</td>
<td>0.03 to 0.04% max.</td>
<td>0.035% max</td>
</tr>
<tr>
<td>Temperature</td>
<td>1450 to 1550°C</td>
<td>1450 to 1550°C</td>
<td>1490 to 1520°C</td>
<td>Not reported</td>
<td>&lt; 1565°C</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Primary difference between hot metal characteristics of FASTMELT and Hismelt is atmosphere in the melter vessel. The FASTMELT EIF atmosphere is essentially all carbon monoxide and, therefore, highly reducing. The reducing atmosphere promotes silicon reduction and sulfur removal. Hismelt must operate with an excess oxygen atmosphere to achieve reasonable post combustion. The oxidizing atmosphere promotes phosphorus removal but prevents sulfur removal and silicon reduction.

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18 COREX POSCO Report
19 Steel Times Int., May 1999, “Redsmelt – Alternative Ironmaking From Demag”
22 Current purchasing specification from U.S. EAF Steelmakers.