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FASTMET® Process for Steel Mill Waste Recycling

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Kobe Steel, LTD. and Midrex Technologies Inc. jointly developed the FASTMET® process as a steel mill waste recycle technology in which the DRI product meets BF feed material or BOF/EAF feed material requirements.
FASTMET® process turns value-less wastes into valuable DRI and sellable zinc oxide, and gives the solution for the steel mill wastes recycling from both economical and environmental viewpoints. During the development of the process, Laboratory, Pilot Plant and Demonstration Plant tests were carried out from 1990 to 1998.
The first FASTMET® commercial plant began operation in April, 2000 and the second commercial plant started in April, 2001. Both commercial plants have proceeded successfully proving that FASTMET® is a suitable process for recycling steel mill waste and for producing DRI as an iron source.

KEY WORDS: dust; waste; recycle; FASTMET; rotary hearth furnace; direct reduction; iron oxide; zinc.

1. Introduction

Kobe Steel, LTD.(KSL) and Midrex Technologies Inc. (Midrex) jointly developed FASTMET® process to establish direct reduction technology through laboratory Tests. Steel mill waste reduction tests were also performed at the Kakogawa demonstration plant (KDP). Most steelmakers are searching for the appropriate ways to recycle steel mill wastes. Accumulation of steel mill waste and their disposal have become worldwide concern. There are two aspects in steel mill waste recycling, one is to recycle valuable resources such as iron bearing materials in steel making and crude zinc oxide in non-ferrous metal recovery, and the other is to reduce environmental pollution.

KSL has proven that the FASTMET® process achieve both high metalization and high zinc removal ratio in waste recycling process through laboratory tests and tests at KDP, which developed the design concept of the first commercial plant. The first commercial plant was constructed and has been working very well. The second commercial plant started at Kobe Steel Kakogawa Works, utilizing KDP for commercial facility.

The FASTMET® process is verified as an attractive proven technology for steel mill waste recycling.

2. Process Description

The FASTMET® processes flow is shown in Figure 1. Steel mill wastes, reductant and binder are mixed and agglomerated into the form of pellets or briquettes. Materials such as BF dust and sludge contain carbon can be used as a reductant. Carbonaceous materials such as pulverized coal and coke breeze are also used if enough carbon is not available in the carbon containing waste materials. Pellets are then dried to remove moisture before feeding to the rotary hearth furnace (RHF). In case of briquettes drying process is not necessary. The pellets or briquettes are fed onto the RHF to form 1-2 layers, then heated to 1,250-1,350 deg. C as the hearth rotates. The reduction process takes about 6-12 minutes during one revolution of the hearth. The direct reduced iron is continuously discharged from the RHF at approximately 1,000 deg. C and treated according to two options.

One of the product options is cooled DRI by water spray, which can be stored, transported and charged as a metallic iron source into blast furnaces (BF), basic oxygen furnaces (BOF) or electric arc furnaces (EAF).
The other option is hot DRI that is loaded from the RHF into refractory-lined DRI container and transported to an adjacent melt shop.

The offgas leaving the RHF is fully combusted and quenched and cleaned in the offgas conditioner. A heat exchanger uses the thermal energy in the offgas to preheat combustion air for the RHF burners and air for pellet dryer.

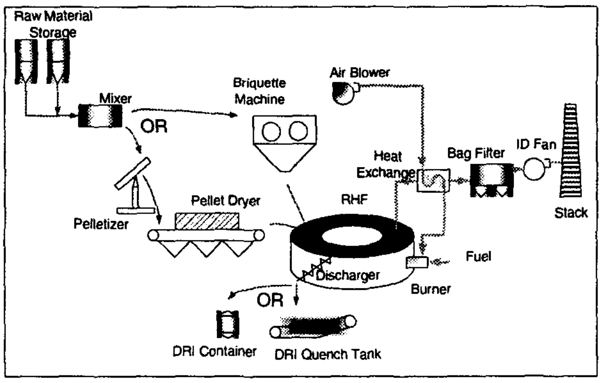


Figure 1. FASTMET® Waste Recycling Processes Flow

3. Development History

FASTMET® is a continuous DRI production process and a descendant of the Heat-Fast process originally developed by Midland Ross Corp., a forerunner of Midrex, in 1965.

In the early 1990's Midrex revived its interest in a coal or solid carbon based reduction process using a RHF. The decision was made to proceed with process development with the intent of commercializing the technology. Due to the short time period required for reduction, and the high metallization levels achieved, the process was deemed FASTMET®.

In order to further development and demonstrate the FASTMET® process, in 1992 Midrex started a 2.2 meter O.D. RHF pilot plant facility at its Technical Center near Charlotte, N.C., USA. The furnace known as the process simulator has provided for practical demonstration of FASTMET® process using a variety of reductant and concentrate mixtures. Since 1992, the Process Simulator has been used to successfully test many raw materials.

In 1994, KSL and Midrex made the joint decision to build a commercial demonstration scale facility with 2.2 tons/h capacity using a 8.5 meter O.D. RHF, called Kakogawa Demonstration Plant at KSL's Kakogawa Steel Works in Japan. The intent was to demonstrate the process on a commercial scale. The plant started operation in late 1995, and a number of campaigns have been run to verify operating parameters, test iron ores, test mill wastes, test reductants, produce product for testing and collect emission data.

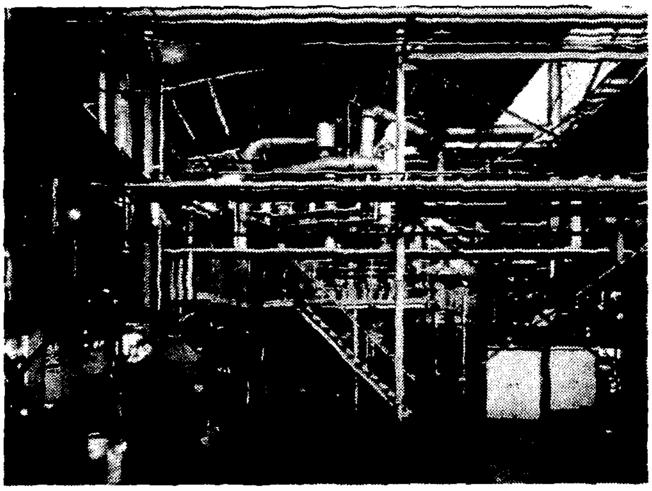


Photo 1 FASTMET® demonstration plant, Kobe Steel Kakogawa works, Kakogawa, Japan

In March 1998, KDP completed two years of round-the-clock operation. Through the continuous and successful operation of KDP, process parameters have been optimized and operational know-how and expertise accumulated to develop a commercial size FASTMET® plant.

As a result of the successful operation of the KDP, the first FASTMET® commercial facility was contructed to Nippon Steel Corporation in early 1999. The facility is located at the Hirohata Works in Himeji, Hyogo Prefecture, Japan. The first product from the plant was produced on March 21, 2000. The plant processes 190,000 tons per year of BOF waste materials into 90% plus metallized product using a 21.5m diameter RHF. The hot DRI is charged to the BOF. Total time from contract signing to plant start-up was 14 months.

The second commercial plant for steel mill waste procesing has been constructed at Kobe Steel's Kakogawa Works. This facility processes 16,000 tons per year of zinc bearing wastes and has started operation since April of 2001.

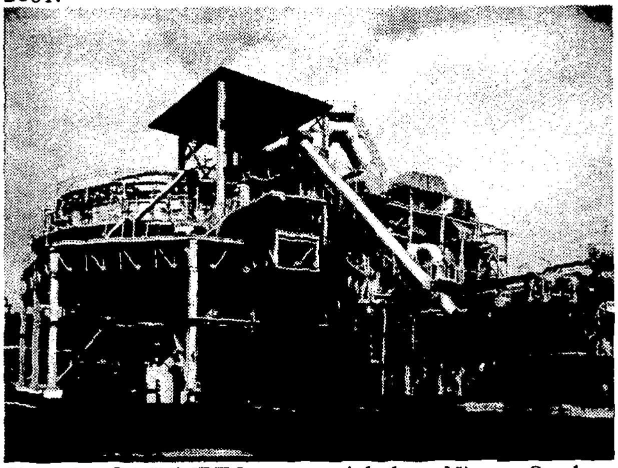


Photo 2 FASTMET®commercial plant, Nippon Steel Hirohata works, Himeji, Japan

3. FASTMET® for waste recycling

In operation of today's steel mill, the steelmaker faces a number of concerns such as:

- Iron bearing waste disposal becomes increasingly restrictive and disposal cost is also increasing.
- Many on-site landfills are filling up and coming under increased scrutiny by environmental authorities.
- Environmental pressure on emission control becomes stricter.
- Disposal of iron bearing waste means disposal of money that the steel maker spend on its purchase of disposed iron.

Both of the BF-based integrated steel mills and EAF-based mini-mills generate a remarkable amount of waste, which is disposed inside or outside the plant. Under the latest trends in environmental protection it becomes more and more difficult and/or expensive to dispose such wastes.

Figure 2 shows a schematic RHF reaction. Inside the RHF, the oxides in the briquettes/pellets are reduced to metals, while heavy metals such as zinc and lead are vaporized and exhausted to the off-gas system in the combustion flue gas. Alkali metals and halogens are also removed from the briquettes/pellets and output to the off-gas system. Thus the DRI produced in the RHF serves as an iron source that contains very little heavy metals, alkali metals and halogens

In the RHF more than 95% of the zinc and lead are liberated from the waste into off-gas, which is collected in an off-gas bag filter. The bag filter dust is a salable zinc-rich material (Zn>60%: This figure was confirmed during the first commercial plant operation)

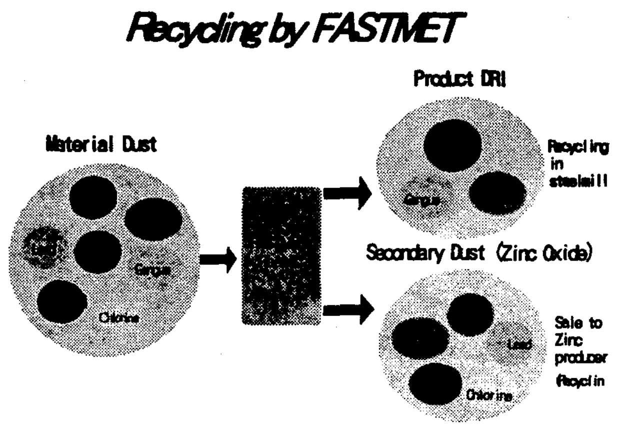


Figure 2. Schematic RHF reaction in the FASTMET® process

3.1 Waste recycling at BF integrated steel mills

An example of waste recycling is to use the BF flue dust, BF and BOF sludge to produce DRI. The BF flue dust and sludge contains 30-40% carbon, and the BOF sludge 60-70 % total Fe. These wastes are mixed in a certain ratio to adjust the carbon balance and DRI quality. The waste and DRI chemical data obtained by laboratory tube test is shown in Table 1. Carbon contained in dusts will be used as a reductant

Table 1 Chemical analysis of BF/BOF waste and DRI

unit : :weight %

Wastes	T.Fe	FeO	C	S	Zn
BF Flue Dust	40.1	19.2	31.0	0.42	0.01
BF Sludge	33.0	10.6	31.4	0.49	0.14
BOF Sludge	63.2	64.4	0.74	0.10	0.43
Product	**T.Fe**	**M.Fe**	**C**	**S**	**Zn**
DRI	70.5	67.2	1.13	0.35	0.004

The produced 70% total Fe DRI and 80-90% metallization can be recycled in the BF or BOF as a metallic iron source, saving coke consumption in the BF operation as well as scrap consumption in the BOF operation.

Some physical FASTMET® DRI properties are presented in Table 2, which were obtained through KDP operation using actually generated waste (Dust A for BF use) and (Dust B for BOF use) from integrated steel mills. These DRI samples have sufficient strength and suitable properties for handling and charging in BF, BOF or EAF.

Table 2 Physical DRI data using BF/BOF waste

	Dust A for BF	Dust B for BOF
DRI compression strength (kg/p)	100-150	50-70
Zn removal ratio	>95%	>95%
DRI fine generation	<5%	<5%
DRI user (recycle to)	BF	BOF/EAF

3.2 Waste recycling at EAF steel mills

EAF dust is a serious issue for steel makers in terms of handling, treating and recycling. The EAF dust is classified as hazardous substance in many countries. Even transportation of it is regulated in many countries and areas. It is preferred to have an economical facility on-site or in the vicinity to recycle EAF dust at each steel mill.

The FASTMET® process has many advantages over the conventional processes to treat EAF dust.

- Very low fine generation in the process realizes high zinc content and very low iron content of secondary dust
- High metallization and high zinc removal make reduced iron product be recyclable at EAF, or BF/BOF if available.
- No waste is generated for disposal.
- High temperature treatment enables to decompose dioxins.
- Low zinc dust can be treated economically. Zinc concentration of dust in the EAF is not necessary.
- Carbon content in DRI can be adjusted as per customer's requirement

Table 3 shows laboratory tube test results of typical EAF dust treatment. Not only iron bearing waste but stainless steel waste containing nickel oxides can also be reduced in the FASTMET® process to produce metallic nickel.

Table 3 Chemical analysis of EAF waste and DRI

Unit :weight %

EAF dust + Coal	T.Fe	M.Fe	C	ZnO	PbO
EAF dust	22.61	0.80	2.69	27.46	0.05
CDQ fine	3.88	0.00	85.42	0.00	0.00
DRI	53.59	51.80	4.67	0.71	0.00

4. FASTMET® process features

In comparison with other waste treatment processes FASTMET® process has the following advantages:

4.1 High Productivity and Quality

One of the most advantageous features of the FASTMET® process is related to the layer arrangements of the loaded pellets/briquettes on the hearth.

The schematic loading arrangement is illustrated in Figure 3 With 1-2 layers pellets are more uniformly heated and reduced, which enables a high furnace temperature and reduction rate control under a relatively short retention time.

On the other hand in the case with more than 2 layers, the temperature difference between upper and lower pellets results in an uneven DRI reduction ratio. It also makes it difficult to maintain a high furnace temperature and reduction rate as the upper pellets easily melt down while the lower pellets are not yet reduced.

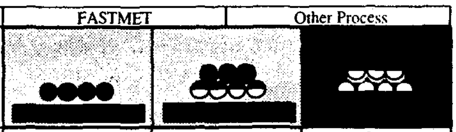
Process	FASTMET		Other Process
Load Pattern in RHF			
No. of Layers	1	2	3
Reduction Temperature	High	◄────►	Low
Retention Time	Short	◄────►	Long
Productivity	High	◄────►	Low
Product Metallization	High	◄────►	Low
Product Uniformity	Uniform	◄────►	Not Uniform
Heat Load to Hearth	Large	◄────►	Small

Figure 3 Comparison of loading method in RHF between FASTMET® process and other processes

As that result, the FASTMET® process provides the following benefits.

- Higher productivity
- Higher metallization :Iron: >90%, Nickel: 95-100%
- Higher de-zincification : 95% or higher
- Uuiform DRI quality

Producing DRI with sufficient individual strength is very important when it is recycled in the BF because they are suitable for charging the BF without generating fines and chips.

Key technologies to realize uniform 1-2 layers are:

- Pelletizing/briquetting technologies including suitable binder selection
- Technologies to control feed rate and leveling performance of the pellets
- Technologies of continuously stable DRI production at very high heat load on the hearth

Producing pellets/briquettes with sufficient strength is an important element of the process. Pellets/briquettes require strength for charging into RHF with minimum generation of fines and chips. Appropriate binders will be selected from the abundant experiences where more than twenty different binders have been tested.

The technologies have been developed to control feed rate and layer level of the pellets through the experiments at test facility and through the operation at the KDP. A number of tests have also been conducted to confirm the charging performances for commercial sized RHF and the system is proven in the commercial RHF.

The pellets on the hearth receive a large heat flux under the high temperature in the furnace. A large heat is also transferred to the hearth underneath due to thinner pellet layers, which can be the source of serious hearth breakage and wear of discharger flights to prevent continuous furnace operations as shown in photo 3. This phenomena is caused by the reduction and compaction of the accumurated fine on the furnace. Development has been extensively extended to the hearth material selection and discharging technology to maintain hearth conditions, which realized to overcome the difficulties and continuous operations at very high heat load on the hearth.

Photo 3 Hearth breakage experienced in the KDP

4.2 High zinc content dust recovery

Due to the zinc and other valuable metals contained in steel mill waste, it is important to provide a means for successful recovery and sale of these by-products. By designing the FASTMET® RHF for minimal iron carryover to the offgas system, a high zinc content dust can be recovered for sale because green pellets/briquettes are fed quietly and do not move on the hearth, thus iron dust generation is kept minimum in the furnace.

4.3 Environment compatibility

In KSL, emission control technologies have been developed through many experience both in incineration plants and iron making plants

The FASTMET® process is developed to be compatible with the 21st century environment. Gas-cleaning system is an important part of the process to ensure the latest dust collection and cleaning technology applied. Water used in the process is recycled and partly utilized through off-gas conditioning system. Dust collected is either recycled back to the system as a raw material or to be sold to refinery for further extraction of valuable metals.

The FASTMET® process eliminates possible formation of dioxins because reaction temperature is high enough in the reduction furnace. Retention time in the furnace is sufficient to decompose dioxins into harmless substances. De-novo synthesis of dioxins during exhaust gas cooling and cleaning can be controlled by a suitable design on temperature parameters. The low emission of dioxins was demonstrated during the commercial plant operations at Kakogawa and Hirohata plants. The emission level was, less than the latest emission restrictions imposed by most developed countries.

5. Commercial Plant Performance

5.1 First Commercial Plant

Through the demonstration plant tests at KDP, it was proven that the FASTMET® process can reduce iron oxide contained in steel mill waste to a very high metalization degree, and simultaneously achieve a very high steel mill waste dezincification degree. These benefits were proven in the commercial plant, the design of which was based on the laboratory tests and demonstration plant tests.

The first commercial plant was built at the Hirohata works of the Nippon Steel Corporation and started continuous operation in April, 2000. The annual dust pellet treatment was 190,000 tonnes. Figure.4 shows the process flow of the first commercial plant. Dust pellets were first dried in the pellet dryer and then fed to the RHF (21.5m in outer diameter). Within a single rotation of the hearth, oxides in the pellets were reduced. Iron contained in the hot DRI is subsequently consumed a succeeding melt shop. Zinc and lead were collected with the flue gas in a bag filter along with alkali metals and halogens.

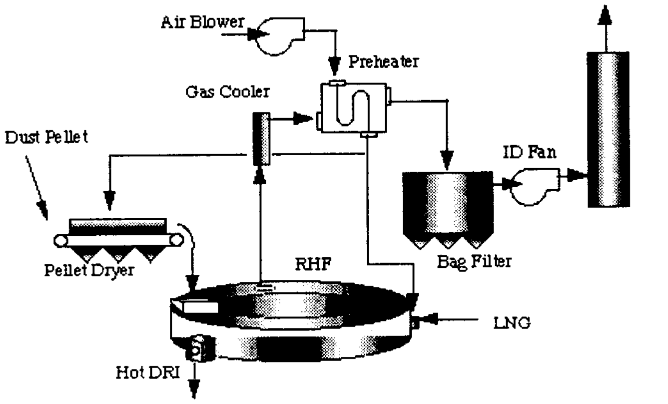


Figure 4 FASTMET® commercial plant process flow

Operation started successfully. Figure 5 shows the hourly waste treatment rate curve. The treatment rate increases smoothly and exceeds the rated capacity. Figure 6 shows the availability of the plant during the continuous operation period. From the time continuous operation started, plant availability has been maintained at a high level.

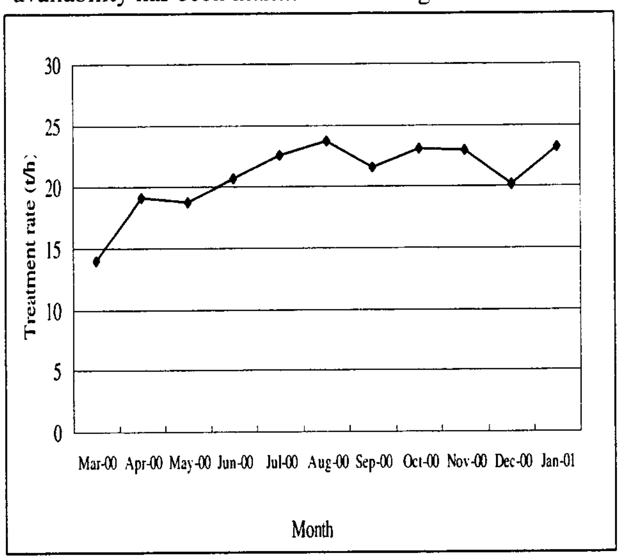


Figure 5 Waste treatment rate

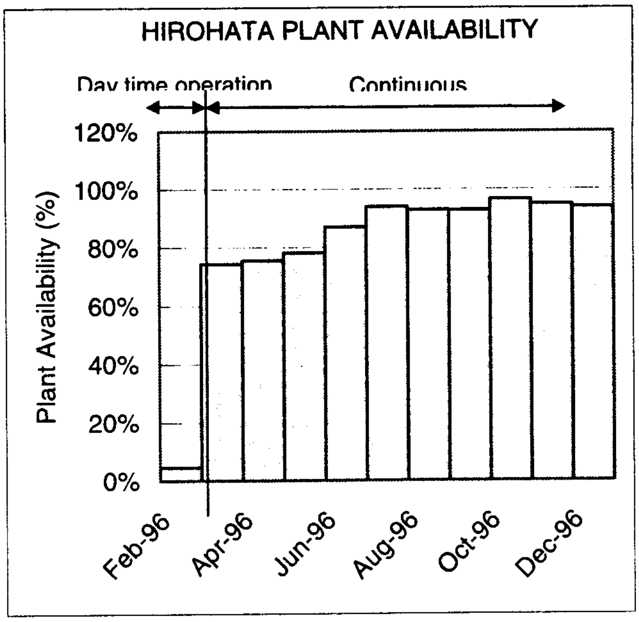


Figure 6 Plant availability

The typical metallization degree in the commercial plant is 91.9% and the dezincification degree is 94.0% at a maximum productivity of 100kg-DRI/m^{2}h, excellently matching the KDP test results.

Table 4 shows the typical zinc content in the flue gas dust. Typically 63.4% Zn content (78.9% as ZnO) by-products are a valuable zinc refinery material source.

Table 4 Chemical composition of the flue gas dust (wt%)

Zn	T.Fe
63.4	1.11

In addition to the above benefits, the first commercial plant also shows that the FASTMET® process is environmentally friendly. The emission limits for all pollutants including dioxin were met. Typical emission data is shown in Table 5.

Table 5 Emission data of FASTMET® commercial plant

	NOx (Nm3/h)	SOx (Nm3/h)	Dust (kg/h)
Guarantee	<3.8	<2.7	<2.09
Actual	1.98	0.08	<0.12

5.2 Second Commercial Plant

The second FASTMET® commercial plant started operations in April 2001 based on a modified version of the KDP. It process 16,000tons of waste annually. The Kakogawa Works has achieved a zero emission rating through operating this plant.

The KDP was modified to reclaim zinc-rich iron oxide dust from blast furnace and steelmaking operations, The offgas unit will be upgraded to recover high zinc content dust. The facility will use waste oil as the primary fuel source as shown in Figure 7.

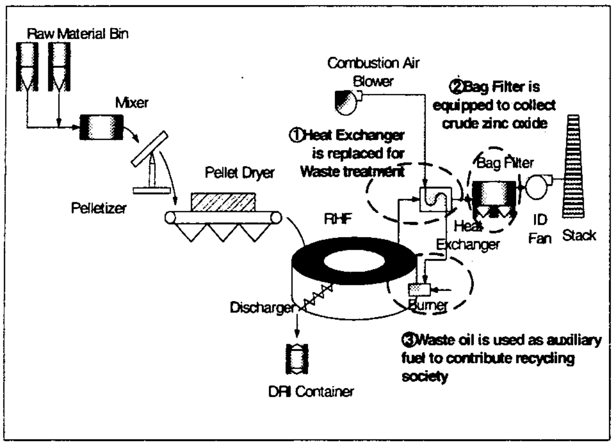


Figure 7 Major modification items of Kakogawa FASTMET® plant

At this commercial plant, the steel mill waste from BF and BOF and the EAF dust are treated, which proves that the FASTMET® process can be used for recycling EAF dust containing high concentrations of zinc. Waste oil can also be used as the auxiliary fuel for RHF burners to maximize industrial waste material recycling.

Details concerning the second commercial plant's are shown in Figure 8.

The high iorn content DRI as shown in table 6 is used in steelmaking operations. And crude zinc oxide recovered from the offgas is sold to the zinc refinery

Table 6. Chemical composition of the dry balls and the DRI

	Dry Ball	DRI
T.Fe (%)	39.8	61.5
M.Fe (%)	0.0	51.9
FeO (%)	53.4	11.9
C (%)	13.3	2.0
S (%)	0.4	0.6
ZnO (%)	4.6	0.3
Metallization (%)	0.0	85%
De-Zn (%)	-	95%

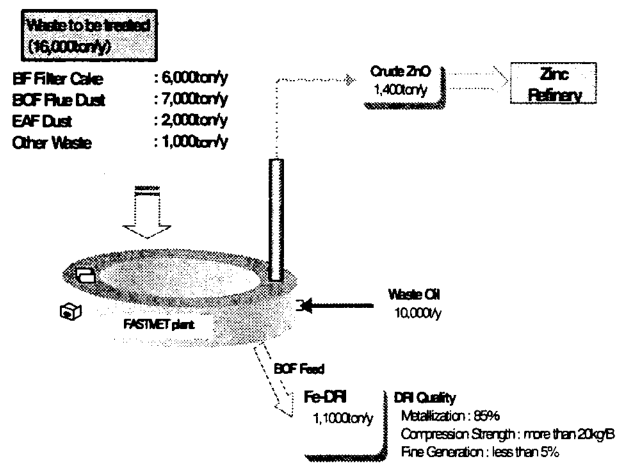


Figure 8 Material flow of Kakogawa FASTMET® plant

6.Conclusions

1. The FASTMET® process creates value-added products from waste currently disposed of or accumulated, thereby saving cost and energy for the existing iron & steel plants, drastically reducing the waste disposition amounts and contributing to environmental protection in steelmaking or metal processing industries.
2. With uniform 1-2 layers arrangement, high temperature operation can be realized and this provides the following benefits.
   >Higher productivity
   >Higher metallization
   >Higher de-zincification
   >Uniform DRI quality
3. The following key technologies to realize uniform 1-2 layers arrangement are developed and patented.
   >Pelletizing/briquetting
   >Feed rate control and leveling
   >Stable RHF operation at very high heat load on the hearth
4. FASTMET® process is verified to be very suitable for dust recycling by the success of two commercial facility.