NEW EAF DUST TREATMENT PROCESS : ESRF

BY

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SYNOPSYS:

Electric arc furnaces (EAF) generate much dust during operation, which contains very high percentages of zinc, lead, and iron, as well as toxic organic substances. It is difficult to landfill it for environmental reasons, and not desirable in terms of wasting metal. However, most of the EAF dust is not processed sufficiently to make it harmless and to recover valuable metals.

Some EAF dust treatment processes are now in use, but the high chloride and zinc content prevents most of them from satisfying environmental regulations and metal recovery.

JP Steel Plantech in Japan and KATEC R&D Corporation in Taiwan have resolved this problem by developing a new electric smelting reduction furnace (ESRF) process. The ESRF is a simple electric furnace, which uses only electric energy for material heating and oxide reduction. In contrast, process gas treatment systems are equipped with a wide range of schemes to prevent chloride and zinc problems.

The first ESRF plant was constructed in Taiwan and started operation in December 2009. This plant is working well as initially intended, achieving high levels of zinc and iron recovery, with no gaseous pollutant emission, and very low leaching of toxic heavy metals from slag.

Keywords : EAF, arc furnace, dust, Zn, ZnO, dioxin, leaching, metal recovery

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1. Introduction

When scrap is melted and refined by an arc furnace, the dust generated accounts for 2 % of the steel production. In Japan, arc furnaces are estimated to generate about 500,000 ton of dust per year during annual steel production of 30 million tons by EAF.

This dust contains many organic toxic substances in addition to metal oxides and chlorides. Metal chlorides and zinc vaporize at the temperature level of 1,300 – 1,500 ºC at which the metal oxides are reduced. When the hot gas from the process passes through gas-cooling and dust-collecting equipment, vapors of metal chlorides and zinc will condense and solidify. This is the main cause of problems in many EAF-dust processing plants.

A new electric smelting reduction furnace (ESRF) has been developed to solve such problems, in addition to recovering metals and conforming to regulations on pollutant emissions and heavy metal leaching.

The ESRF is a simple electric furnace, which uses only electric energy for material heating and oxide reduction. In contrast, process gas treatment systems are equipped with a wide range of schemes to prevent high chlorine and zinc content problems.

The first ESRF plant was constructed in Taiwan and started test-operation in December 2009 and commercial operation in September 2010. The plant is working well as initially intended.

2. EAF dust from steel industry

Table 1. shows an example of the composition of EAF dust. The main components are 20 % zinc, 30 % iron, and 5 % chlorine, and dioxins in EAF dust are reported to be 0.5 -5.0 ng-TEQ/g-dust.

Table 1. Example of EAF dust composition

T-Zn	T-Fe	C	Cl	Pb	Na	K	Mn
22.3	30.9	3.9	5.1	1.9	1.5	1.4	3.0

When dust is processed at high temperature in a lean oxygen atmosphere, metal chlorides are generated. The melting and boiling temperatures of metal chlorides are shown in Table 2. The phase-change temperatures of $ZnCl_2$ are very low, but as the generation of NaCl and KCl is prioritized, a small amount of $ZnCl_2$ is formed during the dust processing. These figures suggest that chlorides are easily liquefied and adhere to the walls of the equipment during gas cooling. This is the main cause of problems in the EAF dust processing at many plants.

Table 2. Melting and boiling temperature of metal chlorides (ºC)

	Melting temperature	Boiling temperature (at 1 atm)
$ZnCl_2$	318	732
NaCl	801	1,465
KCl	772	1,407

Of the 500,000 ton/y of EAF dust generated in Japan, about 60 % is processed by rotary kilns to recover zinc, but the iron in the dust is not recovered by this process. The remaining 40 % is made chemically harmless and disposed of without recovering valuable metals. The dust processing cost paid by EAF companies in Japan is about 220-310 US$/ton-dust, namely 110-155 million US$/y. Another problem is the shortage of space for landfill and disposal.

Zinc is an important metal used as a raw material for strip galvanizing and die-casting alloys. Annual zinc consumption in Japan is about 600,000 tons, 10 % of which comes from the recycling of dust in the steel industry. By improving the zinc recovery rate, this 10 % could be increased to 20 %. As natural zinc resources are limited with less than 25 years' worth of recoverable resources, the recycling of dust should be given greater priority.

3. Conventional Zn recovery process from EAF dust

There are several processes for EAF dust treatment in operation now: (1) rotary kiln (Waelz kiln), (2) rotary hearth furnace (RHF), and (3) multi-stage furnace (PRIMUS). The features of these processes are described below.

(1) Rotary kiln

This is the most common process at present. Four units are working in Japan, one unit in Taiwan, and another under consideration in Korea. Mixed EAF dust and reducing agent carbon are charged into the kiln to be heated by fuel combustion. ZnO in the dust is reduced to Zn vapor in the solid layer, and quickly oxidized to ZnO in the kiln inner space. The ZnO is carried out by exhaust gas from the kiln charge end. The features of this process are:

1) Cheap energy cost

As thermal energy for heating and reduction of oxide comes from fuel combustion without electrical thermal energy, the energy cost is cheap.

2) Relatively large capacity

Small kilns are difficult to operate because of clogging on the inner wall. Relatively large kilns are usually constructed to process the dust from four to six EAFs.

3) Low ZnO % in crude ZnO and high dioxins in exhaust gas

The large volume of combusted gas causes carry-over of the charged material. This carried-over dust is mixed with the ZnO and reduces the ZnO % in recovered crude ZnO to 55-60 %. Also, this carry-over causes the transfer of charged dust to the bag-house without thermal decomposition of dioxins, resulting in high dioxin content in the exhaust gas.

4) High iron oxide, Zn, and Pb contents in clinker from the kiln

A high zinc recovery rate requires high material temperature, but this may cause the softening and sticking of the material in the kiln. As the processing temperature is kept relatively low, the remaining zinc content in the clinker amounts to 2 – 5 %. Fe oxide in the dust cannot be reduced to metallic Fe, and remains as FeO. Landfill or outdoor piling of clinker is not permitted because it contains Pb. Recently, clinker is sent back to the steel mill to be processed by their EAFs, but is not welcomed. This clinker problem is the most serious issue of the rotary kiln process.

(2) Rotary hearth furnace (RHF) and multi-stage furnace (PRIMUS)

Carbon-containing agglomerated dust is put on the moving hearth and heated by combustion heat from above the layer. As in a rotary kiln, ZnO in the dust is reduced to Zn vapor in the solid layer, and quickly oxidized to ZnO in the upper space. ZnO particles are carried out by the exhaust gas from the charge end. Fe oxide is partially reduced to metallic Fe (sponge iron) in the solid state, and melted and refined by the subsequent smelting furnace. This process is widely used for BF dust and BOF dust and more than ten units are working in and out of Japan. However, the process is not yet common for Zn- and chloride-rich EAF dust, due to the following potential problems: (1) chloride solidification and clogging in the gas cooling line, and (2) solidification and adherence of metallic zinc at the bottom of the layer, although detailed results have not yet been reported. In order to avoid the softening of chlorides and sponge iron, the processing temperature should be restricted, which leads to a relatively low metallization degree. The smelting furnace used to melt the discharged material must include a reduction function.

4. New ESRF for EAF dust treatment process

The ESRF is a new process designed to solve the problems found in EAF dust treatment plants. Figure 1. shows the concept of the process. Agglomerated EAF dust is mixed with reducing agent coke and limestone, and charged into the melting furnace to be melted by electric energy. Features of this process are:

(1) Electrical energy is used for heating, melting, and reducing without any fuel. A small amount of waste gas from electrical heating reduces dust carry-over and increases the ZnO content (over 70 %) in crude ZnO, leading to a high selling price to Zn smelter

(2) Thermal energy of the hot exhaust gas is not actively used, only a portion of the

energy is used for preheating the charged material.

(3) Most of the Fe in the dust is recovered as molten pig iron, which is a useful iron source for arc furnaces.

(4) The high gas temperature of over 1250 ºC completely decomposes dioxins and other organic substances in EAF dust.

(5) No hazardous materials remain in the slag, and the leaching rates of heavy metals are very low.

(6) The compact facilities can be installed on-site in each arc furnace plant, and idle facilities such as LF transformers and bag-filters can be used, if any.

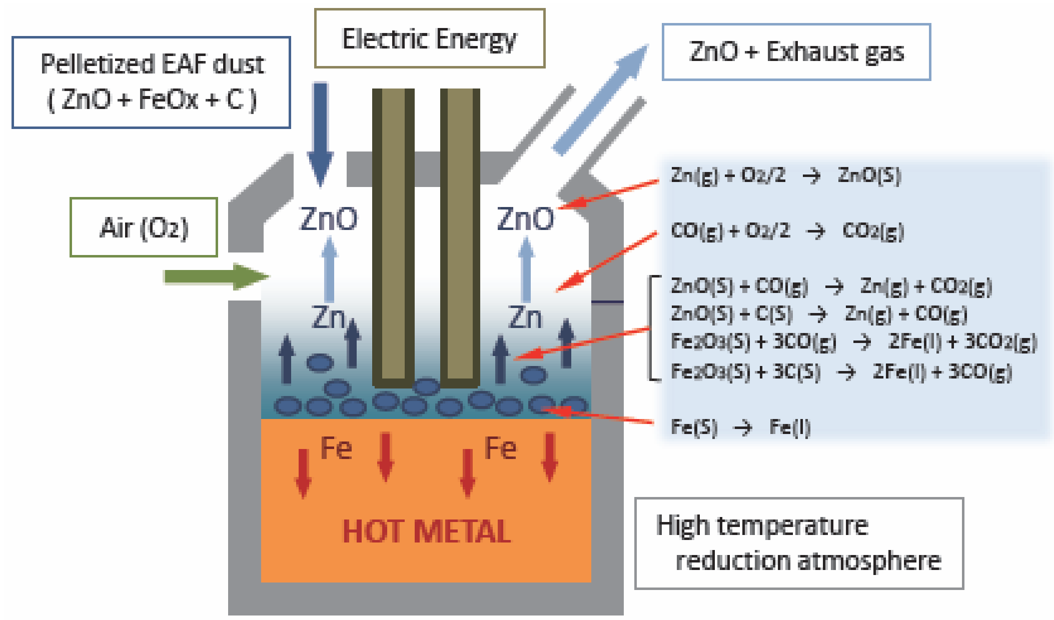

Fig. 1. Concept of ESRF process

There are a few examples of smelting reduction furnaces being used for recovering metals from stainless steel refining dust and others, but many troubles have been reported in EAF dust processing plants caused by chlorides in the dust. Therefore, during the design stage of the new plant, careful attention was paid to the configuration of the exhaust gas cooling and de-dusting device. Figure 2. shows the concept of this exhaust gas treatment system (patent pending).

Carbon monoxide and Zn vapor in the exhaust gas are oxidized in the ESRF and combustion chamber. The combustion chamber is a simple vertical cylinder with water-cooled and partially refractory-lined wall. The vertical water-cooled wall prohibits the adhesion of softened dust and facilitates cleaning. The dimension and insulation are decided to satisfy the design guideline of the incinerator, which is a retention time of at least 2 seconds at a temperature above 850 ºC. Powders of Fe oxide and carbon settle at the bottom of the combustion chamber and are recycled to the ESRF. Particles of ZnO and chlorides are produced by gaseous phase reaction and the sizes are too fine to settle in the combustion chamber. Hot exhaust gas from the combustion chamber, which contains much crude ZnO and chlorides, is quickly cooled through the multi-tube gas cooler and sent to the bag-house to recover the particles. The temperature of the gas cooler is selected to let the chlorides solidify on the vertical tube surface, and so any adhering chlorides can be easily removed. This approach permits prolonged stable operation and good ZnO recovery.

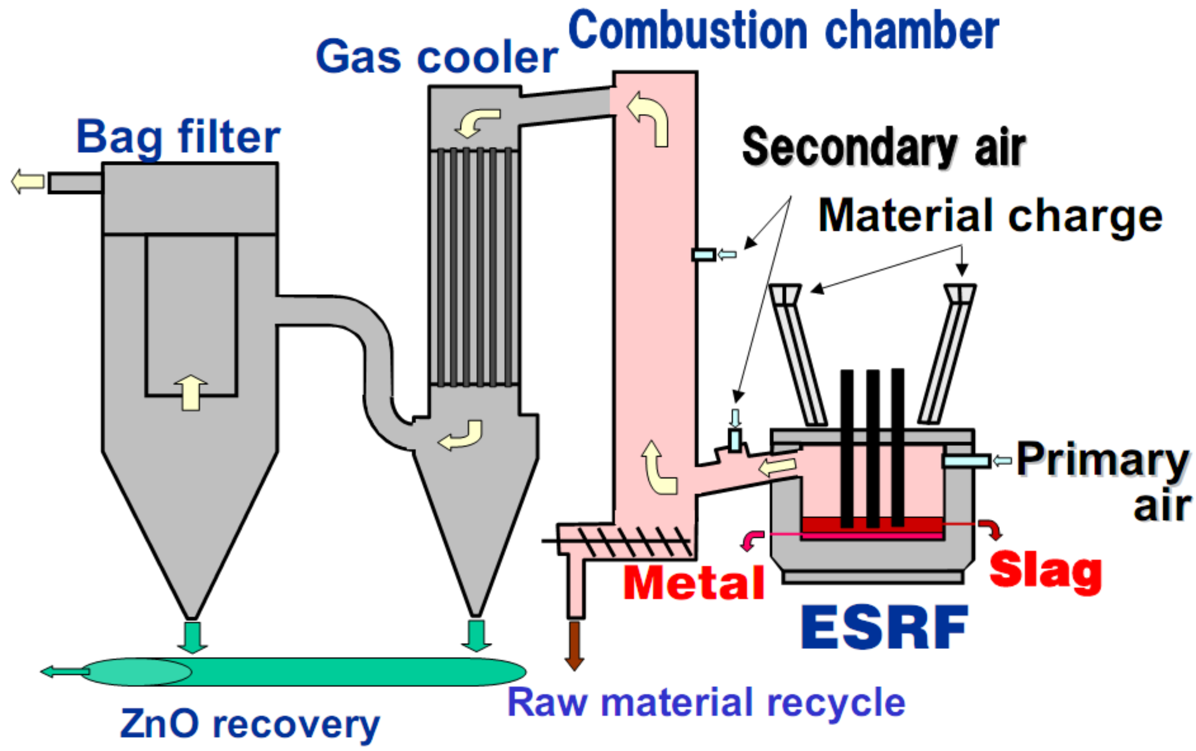

Fig. 2. Concept of ESRF exhaust gas line

5. Development of ESRF and construction of the first plant

(1) Development of ESRF

The first ESRF plant was constructed in Taiwan and has been operating since December 2009. JP Steel Plantech (Japan) and KATEC R&D Corporation (Taiwan) jointly developed and constructed the first commercial ESRF plant as follows:

1) Concept of the ESRF process was developed by NKK (now JFE Steel), based on extensive experience in steel-making EAFs, ferro-alloy submerged arc furnaces, and resistance electric furnaces for melting ash from municipal wastes incinerator. A pilot test was conducted by NKK in the 1990s.
2) KATEC R&D Corporation recognized its advantages for EAF dust treatment and signed a Technical Cooperation Agreement with JP Steel Plantech in 2006. JP Steel Plantech took charge of providing the process know-how and basic design, and KATEC constructed the plant based on this information. The two

companies will jointly promote the technology.

3) A new company KATEC Creative Resources Corp. (KCR) was established to operate the new ESRF plant.
4) Construction started in April 2008, hot-run started in December 2009, and commercial operation started in September 2010.
5) The plant capacity is 5 ton/h (36,000 ton/y) of EAF dust, and the plant can handle other waste such as medical wastes and used dry batteries.

(2) Photographs of the first ESRF plant

Figure 3. shows the main assembly of this ESRF.

Fig. 3. ESRF main unit

The furnace body is not tilted for metal/slag tapping. Tapping holes are opened on the side-wall like a blast furnace. For this purpose, drilling machines and mud guns are provided. Two furnaces are installed, one is working and the other is a back-up. As the spare furnace was not used in the first nine months, a single furnace would be enough for simplification.

Figure 4. shows the EAF dust briquette, recovered crude ZnO, and cast pig iron. When ESRF is installed in an EAF plant, molten pig iron can be directly charged into the EAF, and thus a casting machine to make ingots is unnecessary. This hot liquid pig iron saves energy for the arc furnace.

Fig. 4. Raw material and recovered valuables

(3) Chemical composition of products

Tables 3. shows examples of the chemical composition from ESRF operation. Although these figures fluctuate with variations in the raw material ingredients, the density of ZnO in crude ZnO is higher than those from other processes..

Table 3. Example of chemical composition of recovered valuables

Crude ZnO

ZnO	63.30 %	(50.2–73.7%)
Pb	4.21 %	(0.35–7.22%)
Cd	0.06 %	(0.01–0.18%)
Fe	3.49 %	
Cu	0.13 %	
Si	1.12 %	
Ca	5.18 %	
Cl	6.51 %	
Na	2.46 %	
K	2.35 %	

Pig iron

C	3.29 %
Si	0.47 %
Mn	1.02 %
P	0.36 %
S	0.27 %
Cu	0.47 %
Ni	0.05 %
Cr	1.26 %

Slag

CaO	28.61 %
MgO	9.16 %
SiO2	20.86 %
Al2O3	9.02 %
FeO	2.86 %
Zn	0.48 %
Pb	0.04 %
Cu	0.03 %
Cr	0.54 %

Leaching of heavy metals was measured by both Taiwan standard and JIS. Table 4. shows the results. They are considerably lower than the regulation value of both Taiwan and Japan.

Table 4. Leaching data of heavy metals

KCR ESRF slag leaching data by Taiwan standard (adhering to USA EPA)			Taiwan criteria for landfill
	mg/L	procedure	mg/L
Cd	0.008	USA EPA	1.00
Pb	0.29	USA EPA	5.00
Cr (+6)	N.D.	USA EPA	2.50
Cr	0.014	USA EPA	5.00
Hg	N.D.	USA EPA	0.20
As	0.0012	USA EPA	5.00

KCR ESRF slag leaching data by JIS			Japanese criteria for landfill
	mg/L	procedure	mg/L
Cd	< 0.005	JIS K 0102	0.01
Pb	< 0.005	JIS K 0103	0.01
Cr (+6)	< 0.02	JIS K 0104	0.05
Hg	< 0.0005	other standard	0.0005
As	< 0.005	JIS K 0106	0.01
Se	< 0.005	JIS K 0107	0.01

(4) Recovery rate of valuables and unit consumption

Table 5. shows sample data of the recovery rate of valuables and unit consumption for reference and economic evaluation. Recovery rates also fluctuate with variation in the raw material dust ingredients. Lime is used to control the basicity of slag. If the slag is too alkaline, silica stone is used. The recovered high-ZnO material can be sold to zinc smelters, although EAF dust is disposed of by paying fees at present. The selling price is estimated to be 25 % of the LME price of zinc ingots. The consumption of electrode and refractory largely depends on the operating conditions, but there are no organized statistical data for these costs as yet.

Table 5. Example of recovery rate of valuables and unit consumption

Item	Income & cost	Assumptions and remarks
EAF dust disposal fee	220-310 US$/ton-dust	Reduction of outsourcing cost
Crude ZnO recovery rate	0.35-0.42 ton/ton-dust	Selling price is 25 % of Zn LME price (2,400 US$/ton)
Pig iron recovery rate	0.20-0.25 ton/ton-dust	
Electricity	1,600 kWh/ton-dust	Including aux. equipment
Reducing agent	0.15-0.17 ton/ton-dust	Coke
Electrode, Refractory, Lime	-	No statistical data yet

(5) Typical conditions of ESRF plant in Taiwan

The first ESRF plant in Taiwan was constructed on a greenfield site and planned to receive EAF dust from a number of EAFs, but there were the following disadvantages.

1) New land, building, and utilities had to be newly arranged.
2) An independent maintenance crew and management group were needed.
3) As the site was a newly developed industrial park intended for cleaner production, obtaining approval for construction and operation was complex and time consuming.

JP Steel Plantech recommends that an ESRF plant should be installed within an existing EAF plant to treat in-plant dust. This approach offers the following advantages compared to an independent plant.

1) Existing land, building, and utilities can be effectively used.
2) An additional maintenance crew and management group are unnecessary.
3) Approval for construction and operation is easy.
4) Recycling of molten pig iron to EAF helps save energy.

6. Possibility of multi-purpose melting furnace for industrial wastes.

The ESRF can treat miscellaneous wastes as it is a high-temperature sealed melting device. KCR receives much medical waste from hospitals in Taiwan and incinerates and melts it. Treatment of waste dry batteries is also under consideration. Figure 5. shows the receiving of packed medical wastes and storage in refrigerators. Medical wastes are delivered in 10–15 kg plastic bags, and the bags are charged into the ESRF every 3–5 minutes through a charging chute. The very high furnace temperature ensures quick incineration, and non-combustibles are melted into the slag. There is no hazardous material in the exhaust gas. The disposal of medical wastes is a promising business for furnace owners.

Fig. 5. Disposal of medical wastes with ESRF

7. Conclusion

The ESRF is a revolutionary smelting reduction process to deal with EAF dust. The process solves the problems of environment pollution, unsatisfactory metal recovery, and operation troubles caused by chlorides associated with the old-fashioned dust processing processes. The first ESRF plant started to operate in December 2009 in Taiwan and is working well. The process has great potential to be used in EAF plants worldwide.