Recovery of Zinc

from Electric Arc Furnace

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Electric Arc Furnace

- Working Principle:

An Electric Arc Furnace (EAF) heats materials using an electric arc, with temperatures reaching up to 1,800 °C for industrial units and over 3,000 for laboratory units.

- Types of EAF:

EAFs vary in size from small units for research and dental use to large industrial furnaces for secondary steelmaking. They can be alternating current (AC) powered with three electrodes or direct current (DC) with a single electrode.

- Advantages of EAF:

EAFs offer flexibility in operation, can be rapidly started and stopped, and primarily use scrap metal, reducing the energy required compared to primary steelmaking from ores[^3^][3]. They also result in lower carbon dioxide emissions.

EAF Dust Scenario

- Electric arc furnace (EAF) steel-making, unlike the raw stone steel-making process adopted by blast furnace-converter, is generally based on **smelting scrap steel** and is currently deemed **one of the most important steel-making methods**.
- EAF steel production has accounted for **over 30% of global steel production** and even reached 80% in some developed countries due to their abundant scrap steel.
- Electric arc furnace dust (EAFD) is also among the primary by-products. Many countries have already classified EAFD as hazardous waste for the risk of metal lixiviation, such as zinc, lead, chromium, and other heavy metals.
- The Electric Arc Furnace generates **15 to 25 kg EAFD per ton of steel** by melting scrap steel.
- **8 million tons of electric furnace ash would be generated** at least and most of them would be just stockpiled in steel plants, whereas this part of EAFD could cover about **7% of the world's zinc production .**

EAF Dust Composition

- Table 1 shows an example of EAF dust composition. The main components are 29 % zinc, 27 % iron, and 3 % chlorine, and dioxins in EAF dust are reported to be 0.5-5.0 ng-TEQ/g-dust. Most of the metals in the dust exist as oxides or chlorides.

Element	Concentration (wt%)
Iron (Fe)	27.33
Zinc (Zn)	28.98
Manganese (Mn)	2.74
Calcium (Ca)	2.25
Chlorine (Cl)	3.22
Silicon (Si)	1.51
Potassium (K)	15.49
Oxygen (O)	18.48

Problems of Zinc Recovery

- 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 ZnCl2 are very low, but as the generation of NaCl and KCl is prioritized, a small amount of ZnCl2 is formed during the dust treatment.
- 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

Importance of Zinc

- Zinc is an important metal used as a raw material for strip galvanizing and die-casting alloys.
- As natural zinc resources are limited, with less than 25 years' worth of recoverable resources, the recycling of dust should be given greater priority.
- Zinc content in recovered crude ZnO is higher than that in zinc ore.

Recovery of Zinc

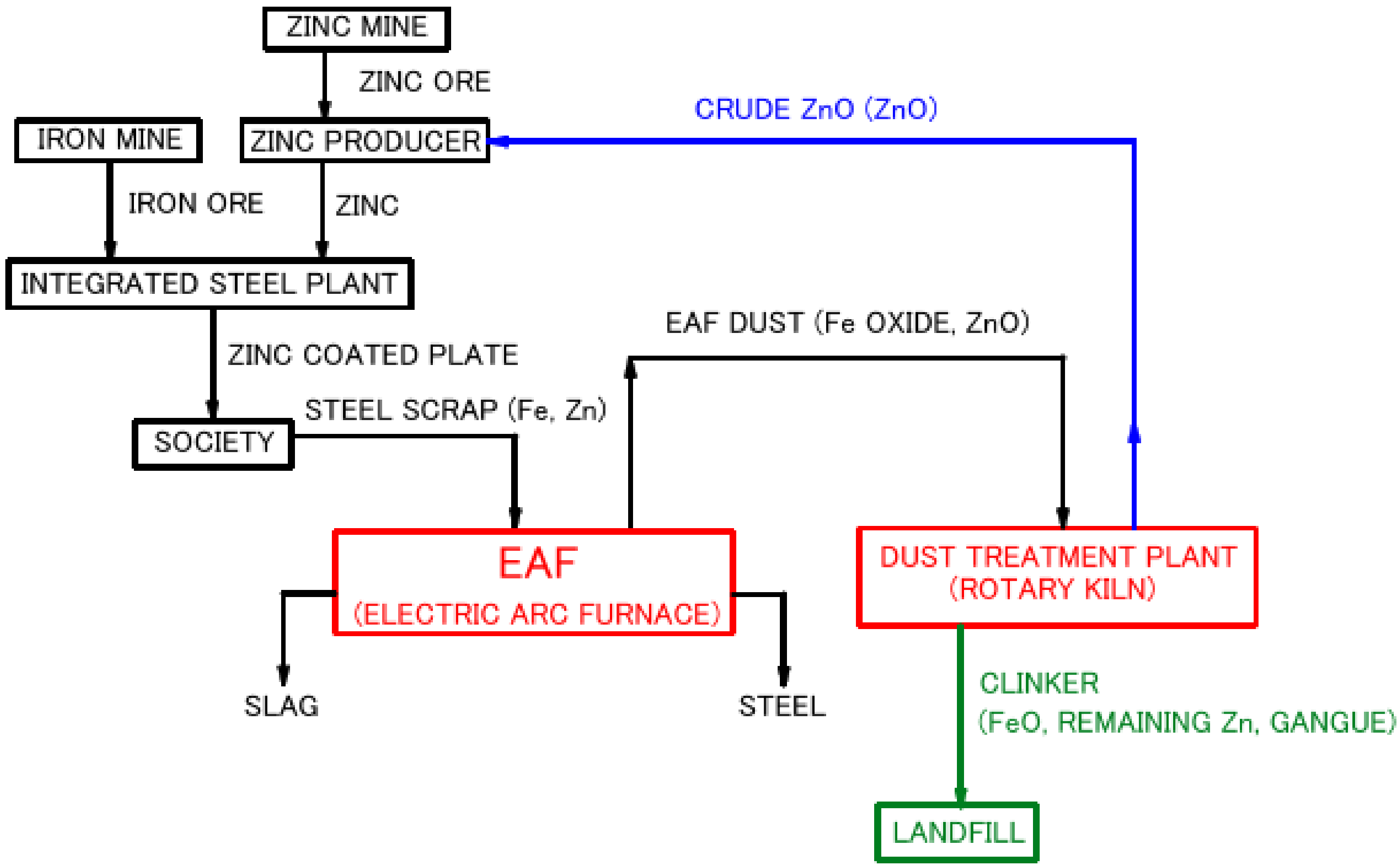
SOLID REDUCTION PROCESS:

- **Gather EAF dus**t generated during steel production, containing Zinc oxide (ZnO), and other impurities.
- Treat the collected dust to remove impurities like C,S and mositure . **Crush and grind** the dust to a fine powder.
- Feed the prepared dust into **rotary kiln** or similar furnace. **Heat it to around 1473-1673K** in an oxygen-deficient environment.
- Zinc oxide (ZnO) in dust reduced to Zinc vapor (Zn) by CO or H2 gas:

Zno + CO (or H2) --------> Zn + CO2 (or H2O)

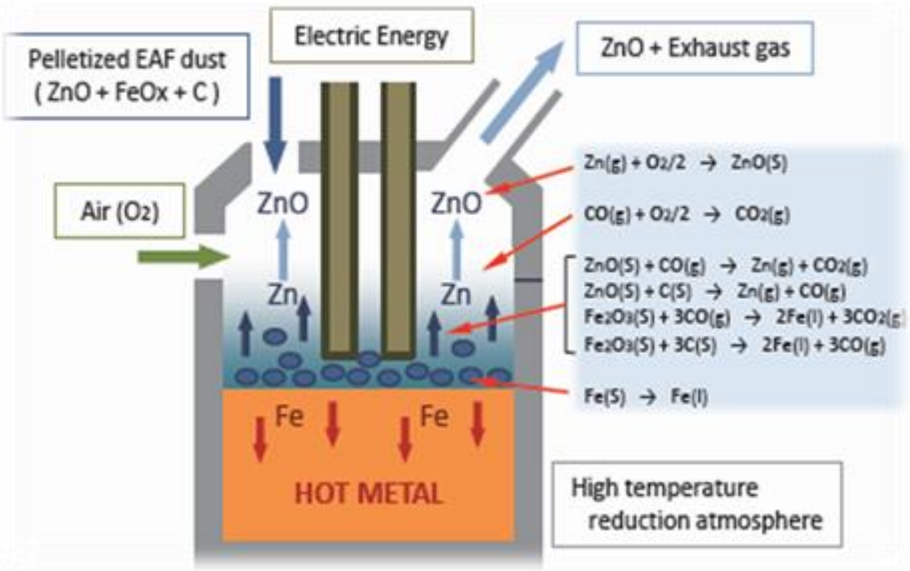
- **Seperate the Zinc vapor** from the remaining solid residues using **distillation or condensation methods** . Collect condensed zinc vapor as **crude ZnO** .
- Manage the remaining solid residues, which may contain partially reduced iron oxide, heavy metals and other impurities.
- Solid Reduction Process is Conventional process.

CONVENTIONAL EAF DUST TREATMENT & METAL RECYCLE



SMELTING REDUCTION PROCESS:

- **Prepare the EAF dust** by removing impurities and ensure uniform composition for smelting.
- Charge the prepared EAF dust, along with coke and limestone (flux), into a **smelting reduction furnace.**

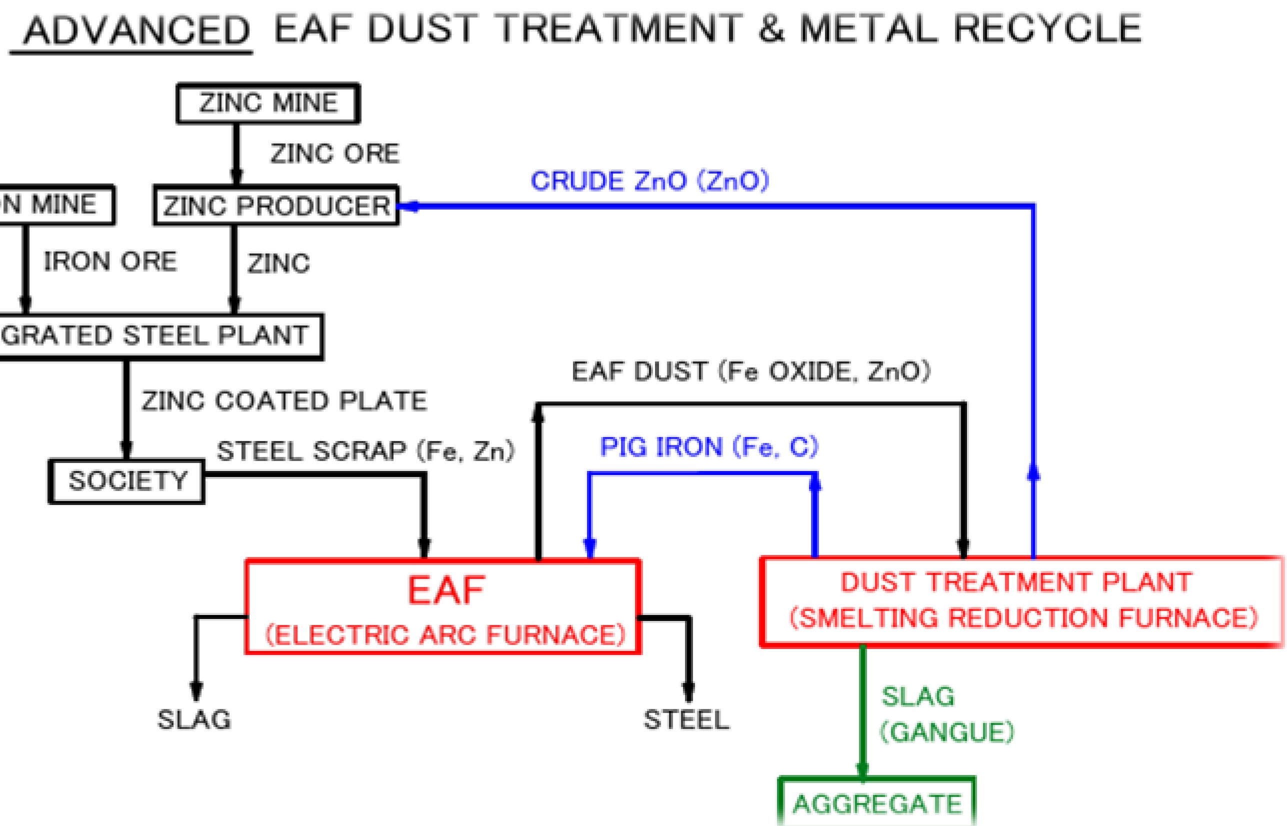


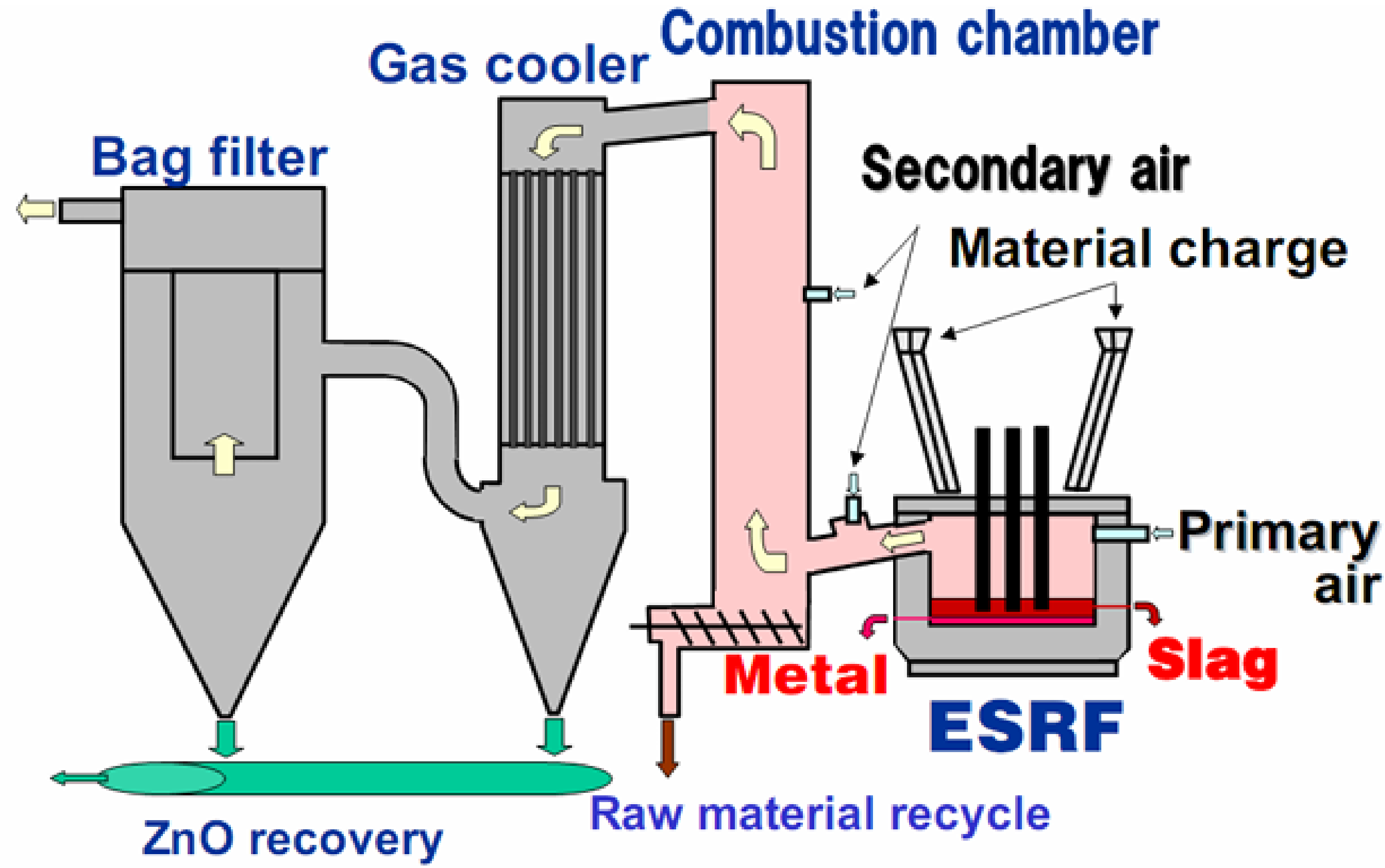
- **Heat the mixture to very high temperatures (over 1773K)** using electrical energy. Achieve complete melting of the materials, including ZnO and other metal oxides.

ZnO + C -----> Zn + Co

Other metal oxides + C -------> Metals + Co

- **Separate the molten metal from the slag** and other impurities. Recover metallic Zn and other usable metals.
- Allow the impurities and non-metallic components to form slag, which floats on top of the molten metal. Slag mainly consists oxides if Si, Ca, Al, and other non-metallic elements.
- **Separate Zn** from the molten material using **distillation** and similar techniques. Condense the Zinc vapor to obtain Crude ZnO .
- **Separate the recovered Zn** and other materials from slag and residual compounds.





Combustion chamber
Gas cooler
Bag filter
Secondary air
Material charge
Primary air
Metal
Slag
ESRF
Raw material recycle
ZnO recovery

ESRF process: It uses a regular method, putting together dust from electric arc furnaces, coke, and limestone into a hot furnace. Special cooling and cleaning tools are set up to handle the exhaust gas. The furnace has a water-cooled wall to stop stuff from sticking. Gas treatment changes harmful gases into harmless ones at high temperatures. Some stuff settles down and gets reused, while other unwanted things are removed in a cooler. The cooled gas matches filter temperatures without using water. The furnace has holes on the side for taking out metal, slag, and leftovers.

Table 3 : Ingredients of Product and Slag (wt%)

- Table 3 lists the components of the recovered materials. The high-carbon pig iron is sent back to arc furnace steel mills for reuse. The slag undergoes slow cooling in a slag pot to form a crystalline structure. This structure, combined with low leaching values of heavy metals like Zn, Pb, and Cd, makes the slag suitable not only for basic landfill disposal but also as construction aggregate.

Crude ZnO

ZnO	68.40 %	(65-82 %)
Pb	4.16 %	(3.8-5.3 %)
Cd	0.09 %	(0.07-0.27 %)
Fe	1.27 %	
Cu	0.10 %	
Si	1.54 %	
Ca	1.64 %	
Cl	4.06 %	
Na	2.85 %	
K	2.29 %	

Pig iron

C	3.44 %
Si	1.65 %
Mn	2.89 %
P	0.27 %
S	0.10 %
Cu	0.72 %
Ni	0.25 %
Cr	1.55 %

Slag

CaO	30.10 %
MgO	2.95 %
SiO2	25.00 %
Al2O3	5.31 %
FeO	2.34 %
Zn	0.44 %
Pb	0.03 %
Cu	0.02 %
Cr	0.19 %

Table 4 shows air pollution data, and Table 5 shows slag leaching data from the ESRF plant in Taiwan. All values are well below regulatory limits, indicating the ESRF process is environmentally friendly.

Particle (mg/m3N)	SOx (ppm)	NOx (ppm)	HCl (ppm)	Pb (mg/m3N)	Cd (mg/m3N)	Hg (mg/m3N)	Dioxin (ng-TEQ/m3N)
55	650	500	60	10	1	0.00352	0.4
1	1.78	2.01	8				
				0.0198	0.00034	0.00026	
							0.007
ND	1.73	2.26	ND	0.0085	0.00009	0.00009	0.011
ND	1.15	ND					
ND	1.12	1.92					0.004
ND	1.65	2.23					
ND	3.19	ND					

Table 4 : Air Pollution Data at ESRF plant

As (mg/L)	Hg (mg/L)	Se (mg/L)	Cr+6 (mg/L)	Cr (mg/L)	Cd (mg/L)	Pb (mg/L)
5	0.2		2.5	5	1	5
0.0012	ND	0.0083	ND	0.014	0.008	0.29

Table 5 : Slag Leaching Data at ESRF plant

Table 6 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	20 kg/ton-dust	Low-grade electrode used

Table 6 presents recovery rates and unit consumption data for economic assessment. Lime and silica stone are used to adjust slag basicity. High-ZnO material can be sold to zinc smelters at an estimated 25% of the LME price of zinc ingots. Adopting the ESRF plant can save arc furnace companies from paying disposal fees for EAF dust.

Profitability

- A feasibility study of 2 ton/h ESRF plant was done to evaluate its profitability.
- 2 ton/h is the minimum practical plant size and is fitted for an on-site plant in an 800,000 ton/y EAF factory.
- Dust generation from the EAF factory is estimated at 12,000 tons/y.
- The study was done for two cases
- 1) in developed countries, where dust treatment fee become unnecessary with the adoption of ESRF, and
- 2) in developing countries, where dust treatment fee is zero at present.

We could come to the conclusion that in both cases, ESRF is profitable. In the case of 2), cheaper electricity prices and lower labor costs contribute to profitability improvement.

- But the dust treatment process should not be discussed from a simple economic viewpoint; the environmental aspect is an important point to consider. ESRF remarkably contributes to reduce air pollution substances and toxic solid wastes.

Advantages

- Smaller exhaust gas volume by electrical heating realizes less carry-over of charged dust and higher ZnO content in crude ZnO.
- Most of the Fe in the dust is recovered as molten pig iron, which is a useful iron and energy source for EAF.
- A high gas temperature of over 1250 ºC completely decomposes dioxins in the charged dust.
- No hazardous materials remain in the slag, and the leaching values of heavy metals in the slag is very low. Slowly cooled slag generates a crystallized structure, and it can be used for many purposes.
- Compact equipment size matches to the on-site plant in the arc furnace factory.

Conclusion

- Increase in recovered metal prices and increasingly severe environmental regulations have required the reevaluation of the EAF dust treatment processes.
- The smelting reduction process was once abandoned, but it has been revised again with the recent changes in the situation.
- New ESRF process is expected to meet the requirements of the society.