ADVANCED SOLUTIONS FOR ENVIRONMENTAL ISSUES IN EAF MELTSHOP

BY

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SYNOPSYS:

Steel scrap, which is used as raw material for electric arc furnaces (EAF), is an essential industrial waste. However, as scrap includes heavy metals and organic matter such as oils, plastics, and paints, EAF operation can cause environmental problems. When scrap is melted in the EAF, dirty gas and particles may be released through gaps in the EAF, and noxious odors and dioxin may be emitted from the baghouse when combustion in the EAF is incomplete. In addition, clinker from EAF dust treatment plants may not satisfy leaching criteria.

Technologies to eliminate these forms of contamination are common to municipal waste incinerators. However, the emission regulations applied to EAFs are less stringent than those applied to incinerators. Part of the reason is that incinerators handle greater amounts of contaminated and odor-producing materials, and are also simple waste disposal operations and not an intermediate process with a useful product, as is the case with EAFs. Moreover, imposition of stricter regulations on the steel industry in one country raises a question of fairness, as it may reduce international competitiveness.

This paper discusses the following three environmental issues common to the EAF meltshop and the technologies to solve them when environmental improvement is required.

(1) Work environment around EAF
(2) Noxious odors and dioxin in exhaust gas from baghouse
(3) Heavy metals in clinker from EAF dust processing plant

Keywords: EAF, arc furnace, environment, dust, dioxin, odor

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1. Introduction

As steel scrap contains materials such as plastics, paints, and heavy metals, environmental pollution can become a problem when scrap is melted in EAFs, and slag and dust from the EAF process also cause problems when buried in landfills. At present, regulations to control such forms of contamination are less stringent than those applied to incinerators, even in developed countries. Whereas operating costs are not necessarily a high priority for incinerators, arc furnaces used to produce steel as a global commodity are always struggling to reduce costs. This paper introduces some of our activities in confronting these environmental issues with the aim of conforming to high-level regulations at a reasonable cost.

2. Work environment around EAF

Steel scrap contains up to 2% of such combustibles as oils, plastics, and paints. Since many EAF meltshops are located in urban areas where scrap is easily obtained, air pollution contained in off-gas emissions from an EAF can sometimes become a serious problem. In Japan, air pollution problems associated with meltshops have been resolved in the last 25 years by fully enclosing the meltshop and installing a large capacity secondary baghouse. However, this has deteriorated the environment of the in-plant workspace. In addition to recent regulation of the concentration of dioxins in baghouse off-gas, the concentration in the workspace atmosphere will be regulated in the near future. Since this problem cannot be solved by simply increasing the flow rate of the dedusting system, we have been systematically changing design and operation criteria based on an investigation of the relationships among the off-gas emission pattern, in-house gas stream, operational sequence of the dedusting system, and floating dust loading of the workspace atmosphere.

(1) Suspended (floating) dust concentration

The suspended dust concentration in the EAF workplace atmosphere was not previously considered quantitatively in meltshop planning. Although a value of, for example, 4 mg/m^3 is sometimes required, such items as the dust particle size, measurement location, measurement method, and use of the peak or average value were not specified. These factors are also indispensable in order to guarantee the required value. Under the Industrial Safety and Health Act, the approved iron oxide dust concentration in the workplace is 5 mg/m^3. The particle size to be measured is <0.00707 mm, which is considered to be the size capable of reaching the human lung. Since the Act prescribes the acceptable average value during working time, the exposed dust concentration can be measured by portable equipment carried by an operator. With this equipment, dusty gas is introduced into a dark box and irradiated with laser light, and the dust concentration is calculated by the strength of the scattered light. This small, portable dust concentration monitor can measure changes in dust concentration every several seconds. We noticed the applicability of this equipment and investigated the relationship between dust concentration and furnace operation. Fig. 1 shows the measuring device used for this purpose (PDM-1010; manufactured by Shibata Kagaku Kikai).

Fig. 1 Digital dust indicator

Monitors are mounted on tripods and placed on the working floor. After several hours, the stored data are transferred to a personal computer. Fig. 2 is an example of this measurement.

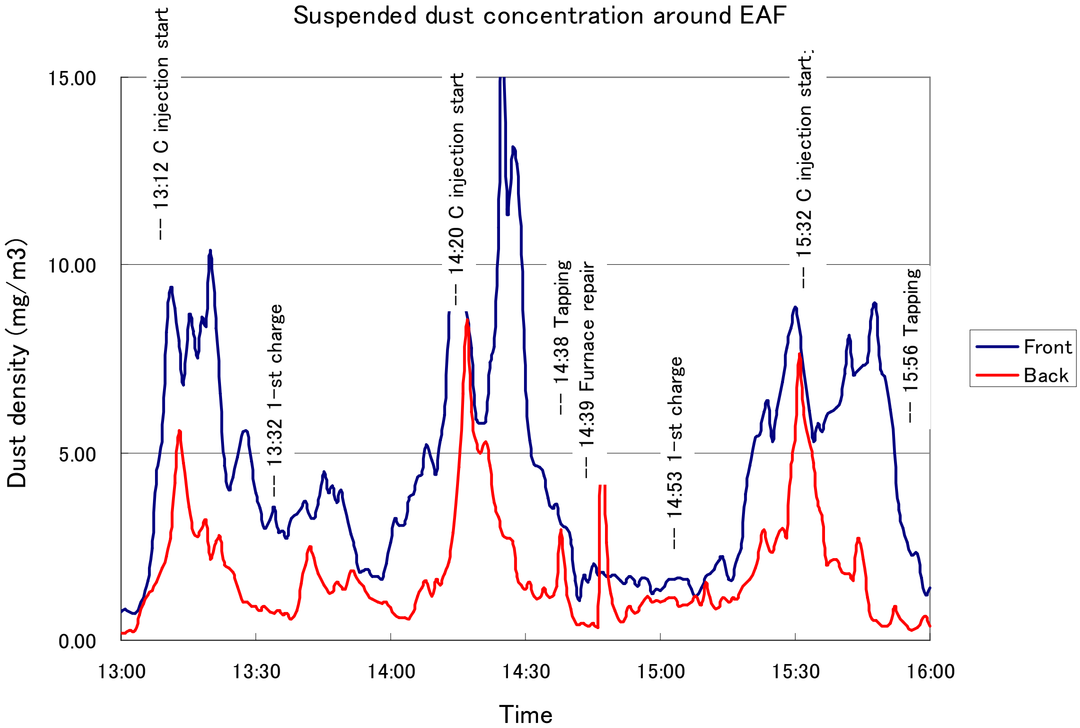

Fig. 2 Change of suspended dust concentration

A : working floor, in front of operating room
B : working floor, near tapping site

The relationships between the dust concentration and furnace operation observed from Fig. 2 are as follows:

1) Dusty hot gas generated during scrap charge forms a strong ascending stream caused by buoyancy. As this stream ascends, the air around the furnace is involved in the stream, reducing the dust concentration in this period.
2) The dust concentration reaches its peak immediately after the commencement of carbon injection. In this period, the off-gas temperature from the furnace becomes very high, and this in turn causes the direct evacuation system to exceed its capacity.

These measurements were made at about 10 meltshops, and the relationships among floating dust concentration, furnace operation, and the specifications and control of the dedusting system were investigated. This information has been effectively used for operation pattern setting, equipment improvement planning, and correction of data for dynamic stream analysis.

(2) Dynamic stream analysis in the meltshop building

An electric arc furnace is a typical batch melter with repeated cycling of operations that include roof opening, scrap charge, roof closing, melting, refining, tapping, and repair during a period of about one hour. The hot dusty gas generated from the furnace causes strong heat convection. As isothermal, static, and potential flow analysis cannot describe the actual stream in the meltshop building, we applied three-dimensional unsteady flow analysis using a high-power computer to meltshop in-house flow analysis and obtained good results. The following is an example from one steel mill in Japan.

Applied method : Finite volume method
Housing size : L 117m x W 55m x H 57 m
Mesh division : 86 x 48 x 41 meshes (169248 elements)
Time division : 0.1 second
Calculation time : from -60 to +600 seconds
Boundary conditions :
1) When the roof is opened, the furnace upper surface becomes very hot.
2) Other heat sources exist, i.e,, the ladle heater and CCM.
3) Suction flow rates through the canopy hoods change according to the settling pattern.
4) Actual measured data of gas temperature, flow rate, and dust concentration during scrap charge are used.
5) A particle size of <0.00707 mm is used to calculate the diffusion and settling velocity.

The calculation outputs are temperature, dust loading, and the gas velocity vector of each cycle time and location defined. Fig. 3 and Fig. 4 are examples which show the dust concentration distribution 480 seconds after the scrap charge. Fig. 4 is the result of a case study of improvement, in which an isolation wall for the CC yard is installed, the ventilation air inlet positions are properly arranged, and the flow rate of air through the canopy hood is increased. The decrease in dust loading resulting from the improvement is remarkable. To date, we have carried out several engineering projects for similar improvement based on this stream analysis.

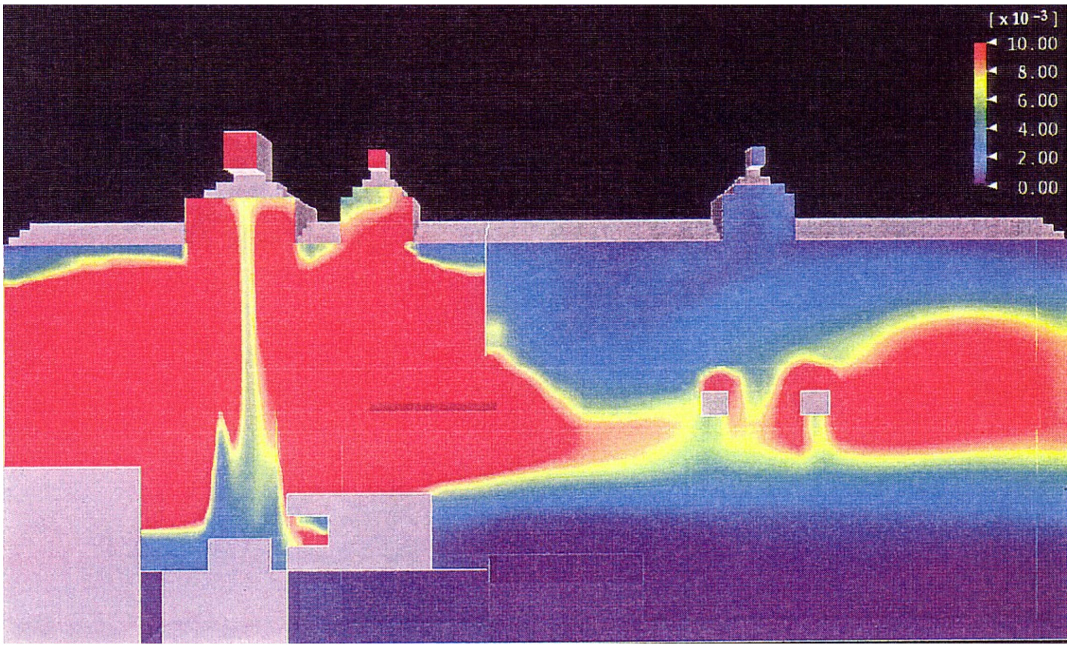

Fig. 3 Floating dust loading before modification

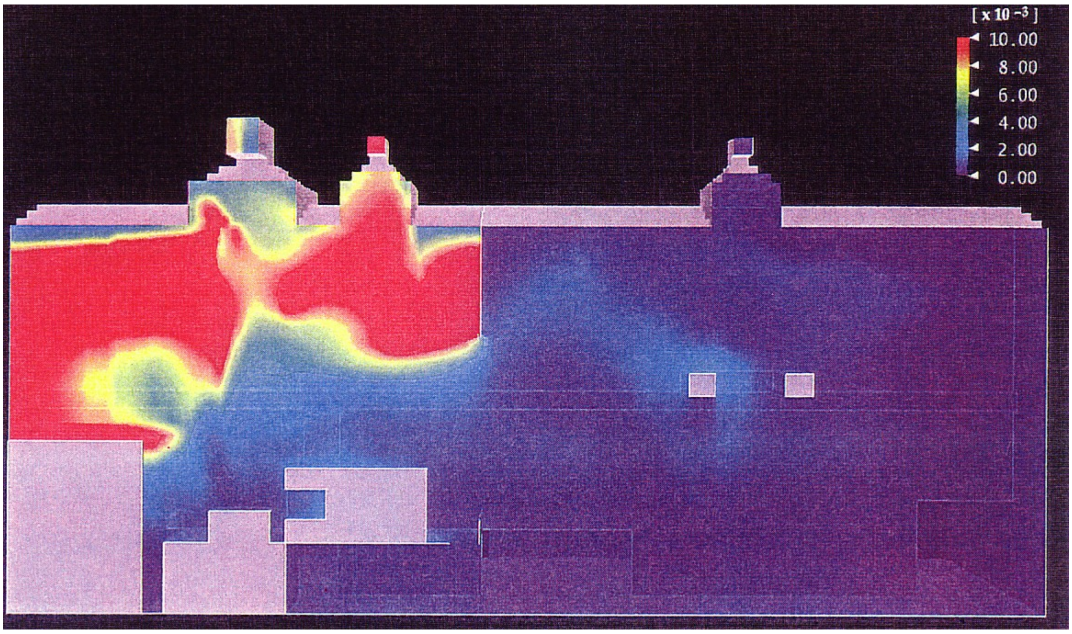

Fig. 4 Floating dust loading after modification

3. Noxious odors and dioxins in exhaust gas from baghouse

(1) Features of dioxins in EAF exhaust gas

Fig. 5 shows the variation in the temperature of EAF exhaust gas. As the scrap contains organic matter such as oils, paints, rubber, and plastics, incompletely combusted organic matter during the low temperature phase generates pollutants. When the performance of the dedusting system is insufficient, noxious odors and dioxins are emitted through the stack. Because measurement of the dioxin concentration in the gas is not only costly but also time-consuming, it is almost impossible to measure and link it to the furnace operation pattern. However, one report stated that dioxin has properties similar to phenol and benzene, and the generation patterns of those materials resemble that of dioxin. Therefore, it can be assumed that dioxin emissions are high when the smells of these materials are perceived.

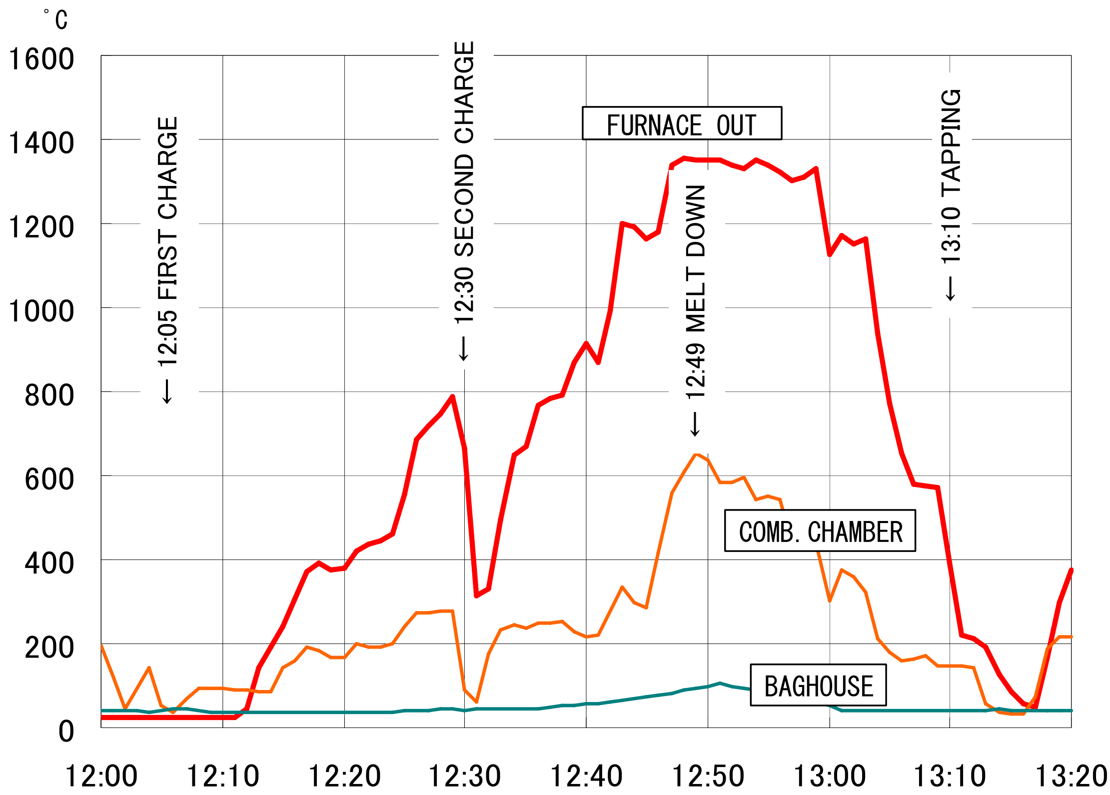

Fig. 5 Variation in temperature of EAF exhaust gas

The following are dioxin sample data measured by the batch method during EAF operation. It should be noted that the measuring point is the furnace outlet port, and not the baghouse.

Early melting stage	: 150 – 200 ng-TEQ/m^{3}N
Late melting stage	: 20 – 70 ng-TEQ/m^{3}N
Refining stage	: 2 – 10 ng-TEQ/m^{3}N

When gas temperature is low, dioxin is easily captured on the bag filter. Fig. 6 is the measured dioxin concentration at the outlet of the baghouse for a typical EAF operation. This pattern is somewhat different from the data of municipal waste incinerators. The reason for this difference is assumed to be the oily material in the scrap and exhaust gas, as oily material condenses on the filter at temperatures below 100°C and absorbs dioxin.

Most of the dioxin generated during the early melting stage is captured at the filter, as the baghouse temperature is low. However, when the process shifts to the refining stage, where the dioxin emission from the furnace is small, the baghouse temperature becomes higher and the once-captured dioxin is released from the filter, resulting in a higher concentration at the baghouse outlet. This phenomenon can be called “hysteresis”. In order to reduce dioxin emissions efficiently, these characteristics of the EAF process should be understood.

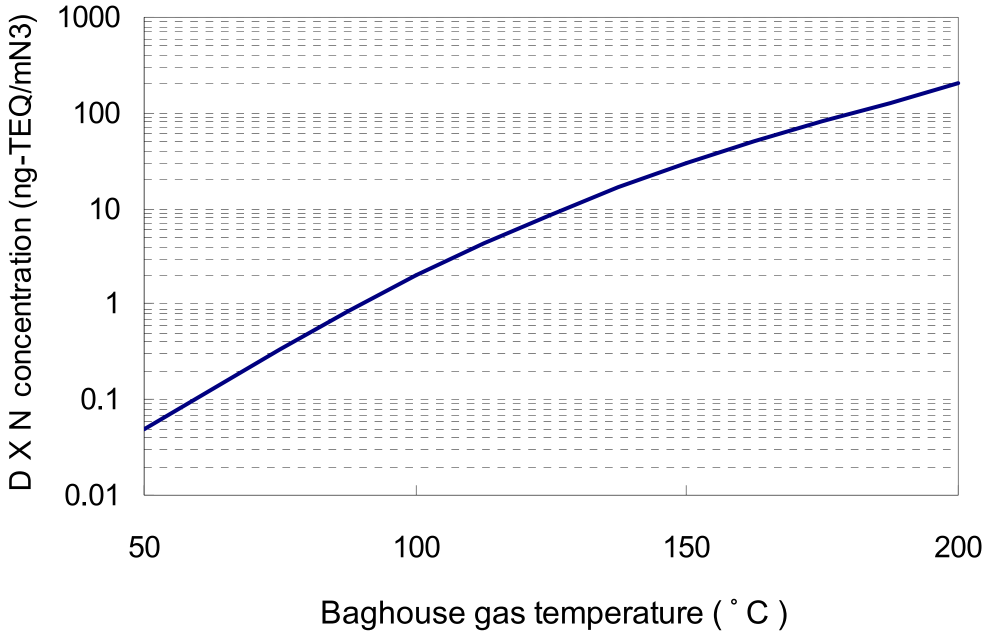

Fig. 6 Dioxin concentration and baghouse gas temperature

(2) Gas treatment technology for dioxin reduction

The design guideline for incinerators is recommended as below in order to achieve the regulatory value of 0.1 ng-TEQ/m^3N.

1) Gas temperature in furnace : over 850°C
2) Hot gas retention time in furnace : over 2 seconds
3) Quick gas cooling to avoid dioxin regeneration
4) For further reduction, use of a catalyst to decompose dioxins or activated carbon injection or bed to absorb dioxins

However, conditions 1) and 2) are not easily met in the EAF process. As seen in Fig. 5, much additional fuel is required to heat-up the cold gas during the early melting stage, and temperature control is not easy due to intense temperature fluctuations. In order to observe the relatively low present regulatory value of 0.5 ng-TEQ/m^3N for EAFs, a gas temperature reduction to <80°C at the baghouse is adequate. This can be realized by reinforcing the cooling capability of the direct evaluation line and mixing this cooled gas into the large volume of the secondary dedusting line. With the semi-continuous charging type EAF, like this company's ECOARC system, the exhaust gas temperature from the furnace is relatively high and is stable. In this case, conditions 1) and 2) become realistic, and a compact gas treatment line becomes acceptable.

However, if more stringent dioxin concentration regulations are applied, e.g., 0.1 ng-TEQ/m^3N as in modern incinerators, method 4) should be used. Many technologies have been proposed so far.

4. Residues from EAF dust treatment plants

(1) EAF dust

When scrap is melted and refined by an arc furnace, the generated dust is equivalent to 2% of the produced steel. In Japan, arc furnaces are estimated to generate about 500,000 tons of dust per year in annual steel production of 30 million tons by the EAF. This dust contains many toxic organic substances in addition to metal oxides and chlorides.

Table 1 shows an example of the EAF dust composition. The main components are 30% zinc, 20% iron, and 5% chlorine; in addition, the concentration of dioxins in the EAF dust is reported to be 0.5-5.0 ng-TEQ/g-dust. Most of the metals in the dust exist as oxides or chlorides.

Table 1 Example of EAF dust composition (wt %)

T-Zn	T-Fe	C	Cl	Pb	Na	K	Mn
32.3	20.9	3.9	5.1	1.9	1.5	1.4	3.0

(2) Dust treatment by solid reduction process

EAF dust treatment is a process which is performed to recover valuable metals from the dust and to make the residue harmless for disposal. Of the 500,000 ton/y of EAF dust generated in Japan, about 65% is processed by rotary kilns to recover zinc, but the remaining 35% 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$/ton-dust, or 110-155 million US$/y for all of Japan. The existing dust treatment plants are classified into two groups, namely, 1) solid reduction process and 2) smelting reduction process. Both processes reduce zinc oxide in the dust to zinc vapor in order to separate it from the residue. The solid reduction process does not melt the iron oxide, and partially reduces it to FeO, whereas, the smelting reduction process melts down and reduces almost all the metal oxides in the dust.

The solid reduction process uses combustion energy as the energy source. Although this energy is cheaper than electrical energy, because the exhaust gas volume is larger and the carry-over of charged material is high, the concentration of ZnO in the recovered material is diluted. In addition, the lower reaction temperature cannot realize complete reduction of iron oxide and removal of heavy metals from slag and clinker. Fig.7 shows the concept of the solid reduction process.

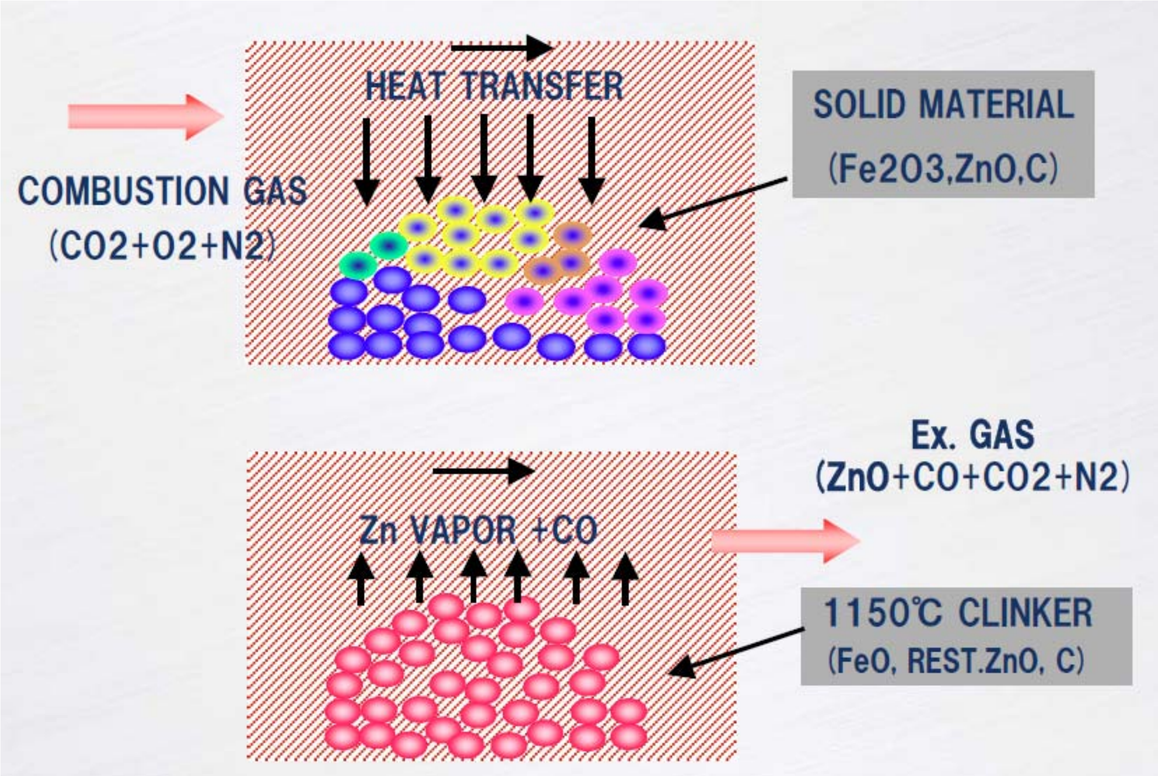

Fig. 7 Concept of solid reduction process

The only commercialized solid reduction technology is a rotary kiln process called the Waelz Process, and tens of units are in operation around the world. While this is a proven and profitable process, the huge volume of clinker discharged from the kiln is a problem at many plants. A noteworthy figure is the Pb content of 0.40%, which exceeds the regulatory value accepted for landfills or use as aggregate for construction. In the case of rotary kilns in Japan, this clinker is returned to the EAF meltshops to be melted and reduced again, but this causes a considerable increase in electric power consumption.

Table 2 Example of kiln clinker composition (wt %)

Zn	T. Fe	M. Fe	Pb	SiO2	CaO	C	Cu	Al2O3
5.50	52.00	28.00	0.40	8.50	3.80	3.50	0.40	4.20

Sn	MgO	Cl	S	Na	K	T.Cr	MnO	P
0.05	2.40	0.16	0.60	0.75	0.20	0.50	4.70	0.13

(3) Dust treatment by smelting reduction process

The alternative for solving this clinker problem is the smelting reduction process. Smelting reduction uses electrical energy to heat and reduce metallic oxides in the EAF dust. The very high temperature produced by electricity melts down all the materials in the dust, which makes it possible to recover iron as metallic Fe and to realize a very high separation rate of heavy metals from the slag. As no fossil fuel is used, the exhaust gas volume is smaller, which realizes a low dust carry-over rate. Therefore, the ZnO percentage in the crude ZnO is higher than that in the solid reaction process. Fig.8 shows the concept of the smelting reduction process.

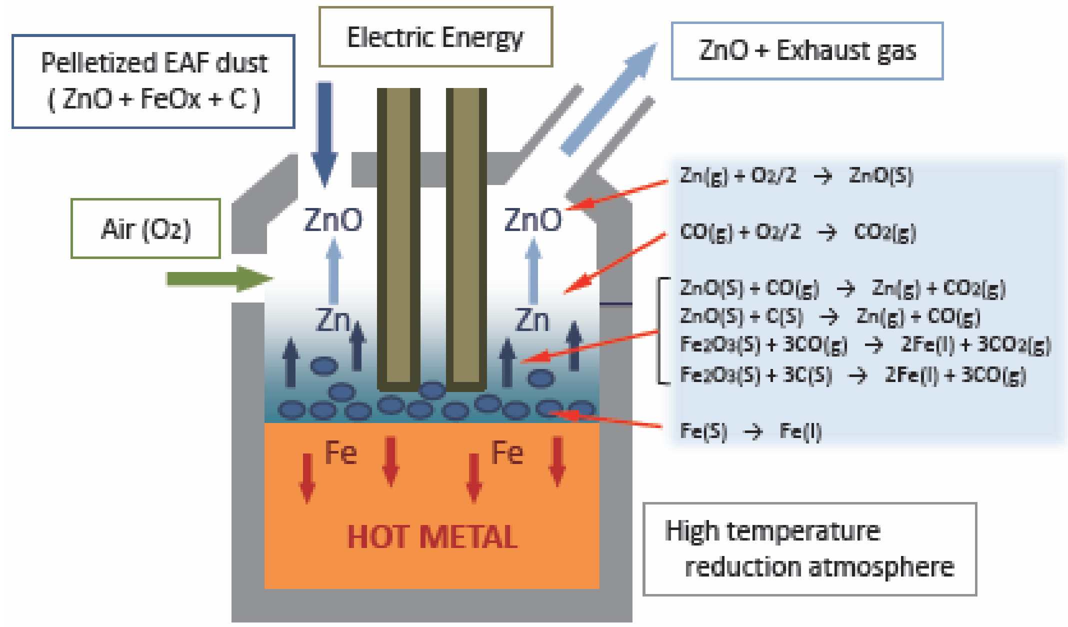

Fig. 8 Concept of smelting reduction process

Although the energy cost is higher than that in the solid reduction process, the advantages of a high Zn and Fe recovery rate can compensate for this increase in the operating cost. The saving of dust treatment fees paid to outside contractors is also a significant advantage, as this type of facility is compact and can be constructed on-site within the EAF meltshop. Table 3 shows the ingredients in the recovered materials. High-carbon pig iron is returned to arc furnace steel mills. Slag is cooled down slowly in the slag pot to generate a crystallized structure. In addition to this crystalline structure, very low ingredient values of heavy metals such as Zn, Pb, and Cd allow this slag to be treated by simple landfill or use as aggregate for construction.

Table 3 Ingredients of product and slag (wt %)

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 %

Average data 2011 Jan. - Apr.

5. Conclusions

EAF steelmaking plants, which process dirty raw material scrap, are under increasing criticism from the viewpoint of environmental protection. Although the current regulatory values applied to EAFs are still less stringent than those applied to incinerators, engineers must develop reliable, economical technologies to solve environmental issues in anticipation of much more rigid requirements in the future. This paper introduced three major subjects, improvement of the EAF working environment, reduction of odors/dioxins in baghouse exhaust gas, and measures for treatment of EAF residues containing valuable metals and heavy metals. As described herein, effective technical solutions to these problems have been developed by JP Steel Plantech, which is a major EAF supplier.