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EAF Dust Recycling Technology in Japan

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1. EAF Dust in Japan - Generation and Characteristics
The quantity of dust generated from EAF shops in Japan was estimated to be 520,000 tons/year in 1999. Extremely fine dust (or fume) is formed in the EAF by metal vaporization. Its characteristics such as chemical compositions, phases, particle size, leaching of heavy metal are mentioned.
2. EAF Dust Treatment Methods in Japan
In 1999, 61% of EAF dust was treated by regional zinc recovery processing routes, 25% went to landfill disposal, 4% was reused as cement material, and 10% was treated by on-site processing routes. The problems of EAF dust treatment methods in Japan are: (1) very high treatment cost, and (2) heavy environmental load (leaching of heavy metal, emission of dioxins, depletion of disposal sites, etc). It has been much hoped for that new dust management technology would be developed.
3. New technology of EAF dust treatment in Japan
In Japan, some new technologies of EAF dust treatment have been developed, and some others are in the developing stages. Following five processes are mentioned:.(1) Smelting reduction process by Kawasaki Steel, (2) DSM process by Daido Steel, (3) VHR process by Aichi Steel, (4) On-site dust direct recycling technology, and (5) Process technology of direct separation and recovery of iron and zinc metals contained in high temperature EAF off gas by the Japan Research and Development Center for Metals.
Key Words: EAF dust treatment, Recycling technology, Zinc recovery

1. Introduction

Large quantities of useful resources such as iron and zinc are contained in dust generated from EAFs.
While it is desirable to recycle such metals, the presence of chlorides, lead, and other impurities in the dust stands in the way of efficiently recycling these metals. Against such a backdrop, the amount of dust generation, its characteristics, and dust processing methods are described in this paper.
New technologies developed for processing EAF dust in Japan are introduced, and directions to be taken in the future are discussed.

2. Generation and Characteristics of EAF Dust in Japan

1) Generation

The quantity of crude steel produced via the EAF route in Japan totaled 99 million tons/year in 1999. The rate of EAF dust generated per ton of crude steel production was 18.3 kg.
Total dust generation from EAF shops in Japan was estimated to be 520,000 tons/year in 1999.
Past surveys indicated that the rate of EAF dust generated per ton of crude steel production was 15 kg in 1995, but rose to 17.4 kg in 1997. Therefore, it can be seen that the unit generation of EAF dust had increased during this five-year period.
The breakdown of the average figure of 18.3 kg/t-steel in 1999 is 18.5 kg/t-steel for carbon steel, and 15.5 kg/t-steel for special steel.

2) Chemical Composition

EAF dust from 16 EAF shops in Japan was analyzed in 1995. Average values are given in Table 1. [1]
It is estimated that zinc and chlorine have seen further increase in more recent years.

3) Particle Size

Typical particle size of EAF dust is shown in Fig. 1. [2][3] It is extremely fine dust from 0.1 μm to 10 μm in size. Fine dust is very difficult to handle, and in some cases it is pelletized to prevent it from flying about, especially while it is being transported.

Table 1 EAF dust chemical compositions (%)

Zn	Fe	C	P	Cr	Mo
22.5	32.0	3.6	0.10	0.36	0.03
Ca	Cl	Cd	F	Ni	Si
2.6	3.1	0.02	0.25	0.03	1.6
Cu	Sn	Pb	Na	K	Mg
0.20	0.05	2.2	1.0	0.5	1.15
Mn	Al	O	Total		
2.6	1.1	25.0	100		

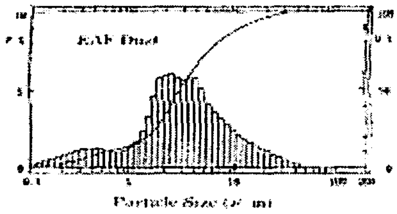


Fig. 1 Typical particle size of EAF dust

4) Dioxins in EAF Dust

Dioxins contained in EAF dust generated in Japan are 4ng-TEQ/g. Therefore, additional technologies for reducing the amount of dioxins contained in dust are necessary when the effects of dioxins contained in off gas released from the Waelz kiln method or dioxins contained in landfills are taken into consideration.

5) Leaching of Heavy Metals

EAF dust leaching tests reveal that heavy metals such as lead, cadmium, and hexavalent chromium leach out. Therefore, heavy metals must be subjected to chemical treatment to render them harmless before landfill disposal.

6) Phase of Zinc

ZnO and $ZnFe_2O_4$ are the main phases of Zinc. It appears that $ZnCl_2$ is also present.

The rate of Zn that is present in the ZnO phase varies according to the Zn and Fe content, and the composition and temperature transition of off gas flowing from an EAF to a dust collector. Generally ZnO and $ZnFe_2O_4$ are present at a rate of 70% and 30% respectively, while $ZnCl_2$ is present at a level of about several percent at the most. [4]

Since $ZnFe_2O_4$ does not dissolve in alkali, it becomes a critical problem in wet treatment.

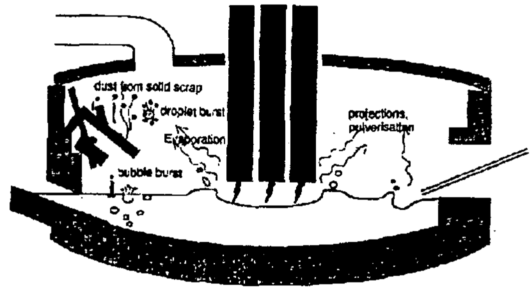


Fig. 2 Mechanism of EAF Dust Generation

7) Dust Generation Mechanism

Birat et al of IRSID of France shows the mechanism of EAF dust generation as illustrated in Fig. 2. [5]

Majority of metal- and slag-based dust is generated by bubble burst. It is stated that dust based on volatile components such as zinc, lead, and chlorides is generated by vaporization.

The author et al investigated the dust directly sampled from the break-flange section of an EAF by rapid cooling The results are shown in Fig. 3, which reveals that Fe is present in the EAF in the form of FeO or alpha Fe, while practically no Fe_2O_3 is preset. Zn is present in the form of Zn or ZnO, but practically no $ZnFe_2O_4$ is present. The results further reveal that particle sizes range from 30 to 300 nm. It is a size range more appropriate to call fume rather than dust. Therefore, it was assumed that some reaction and aggregation were taking place in the process of going from the combustion tower to the dust collector. [6]

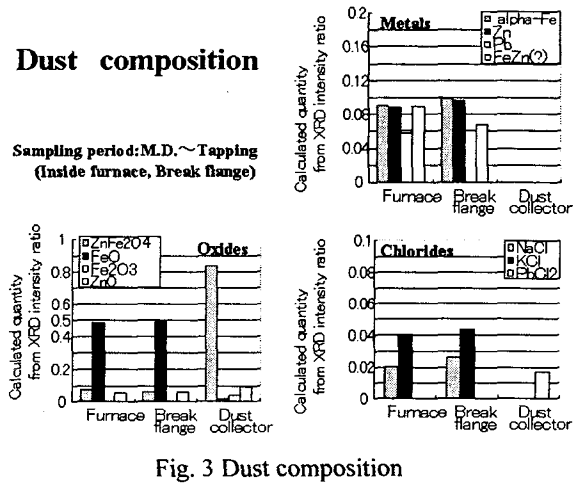


Fig. 3 Dust composition

Behavior of chlorides was experimentally assessed by thermodynamic equilibrium calculations. The results are shown in Fig. 4, which reveals that they are present in the furnace in gaseous phases of NaCl, KCl, and HCl. It was assumed that $CuCl_2$, NaCl, KCl, $PbCl^2$, and $ZnCl_2$ precipitate when the temperature lowers.

These chlorides eventually precipitate on the surface of Fe-based particles. It is needless to mention that care must be exercised in this regard since their behavior varies according to chemical composition, gas components and temperature.

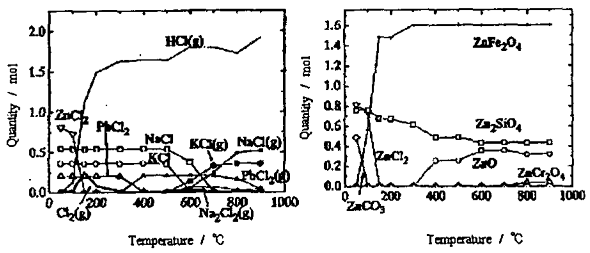


Fig4-1 The behavior of Zn   Fig.4-2 The behavior of Cl

Fig. 4 Behavior of Zn and Cl

By recognizing the dust generation mechanism as above and controlling the dust in respective processes accordingly, the treatment in the downstream processes is made easier. It is gratifying to learn that research has been started on these dust-controlling technologies.

3. EAF Dust Treatment Methods in Japan

1) Status of EAF Dust Treatment

The status of EAF dust treatment in 1999 is shown in Fig. 5 and table2. The processes used by toll zinc recycling operations are shown in Table 1 and Fig. 6. The "Others" block in Fig. 5 supposedly includes the captive recycling process of Ni and Cr contained in SUS dust, direct recycling of EAF dust, captive process of making slag out of dust, etc.

Therefore in total, zinc is being recycled from 71% of dust by toll zinc recycling operations and other types of recycling operations.

The outline of the Waelz kiln method is schematically illustrated in Fig. 8. [4][7] The outline of an electric distillation method is shown in Fig. 9. [8]

The outline of the Mitsui furnace method is shown in Fig. 10. [1]

The outline of the process for changing dust into raw material for cement is shown in Fig. 11. [9] This process uses Fe_2O_3 contained in the dust as raw material for cement.

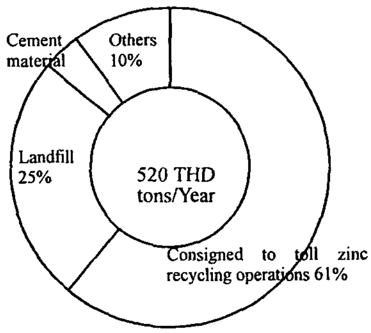


Fig. 5 Status of EAF Dust Treatment

Table 2 Zinc Recycling Plants in Japan

Process names	Operators	Capacity (t/y)	Disposition of processed materials
1) Electric distillation method	Toho Zinc's Onahama plant	50,000	Zinc oxide (99.5% ZnO) used as rubber additive; Residue returned to EAF.
2) Waelz method	Sotetsu Metal	60,000	Crude zinc oxide is sent to Nisso Kinzoku Kagaku located nearby to remove lead and halogen for use as ISP material; Residue used as cement material and roadbed material.
	Himeji Iron and Steel Refining	50,000	Crude zinc oxide used as ISP material; Remainder purchased by steelmakers.
	Sumitomo Metal Mining's Shisaka plant	120,000	Crude zinc oxide is used as ISP material after halogen is removed; Residue is disposed of as landfills
3) Mitsui furnace method (MF method)	Miike Smelting	120,000	Crude zinc oxide is used as ISP material; Mat is sent to copper and silver smelters; Slag is crushed by water cooling and used as cement material.

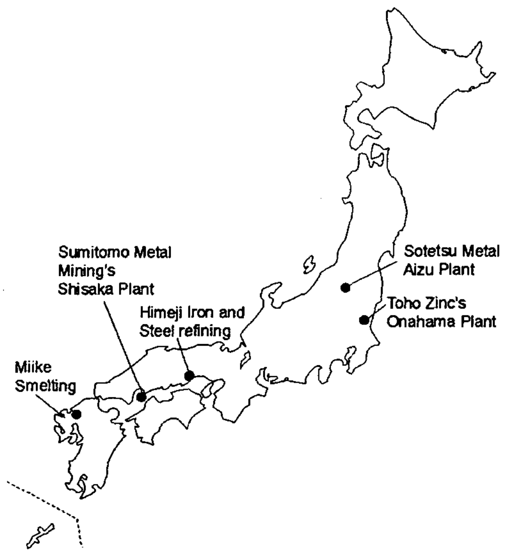


Fig. 6 Location of Zinc Recycling Plants

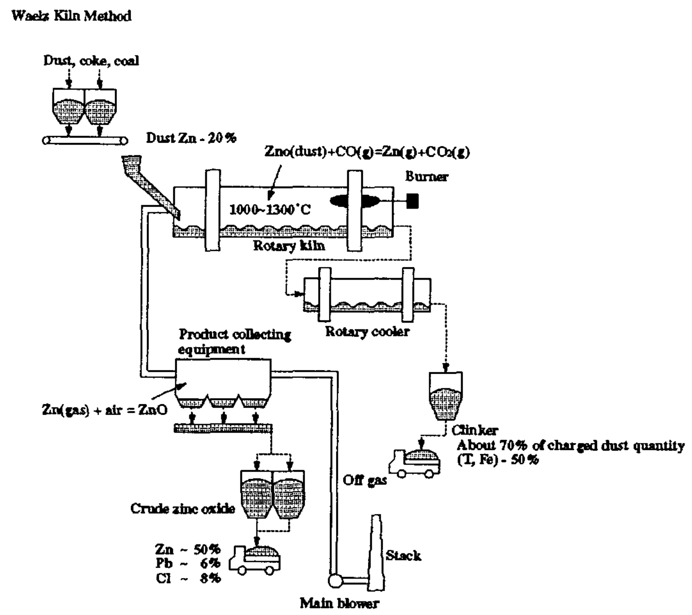


Fig. 7 Process flow of Waelz kiln method

Electric Distillation Method

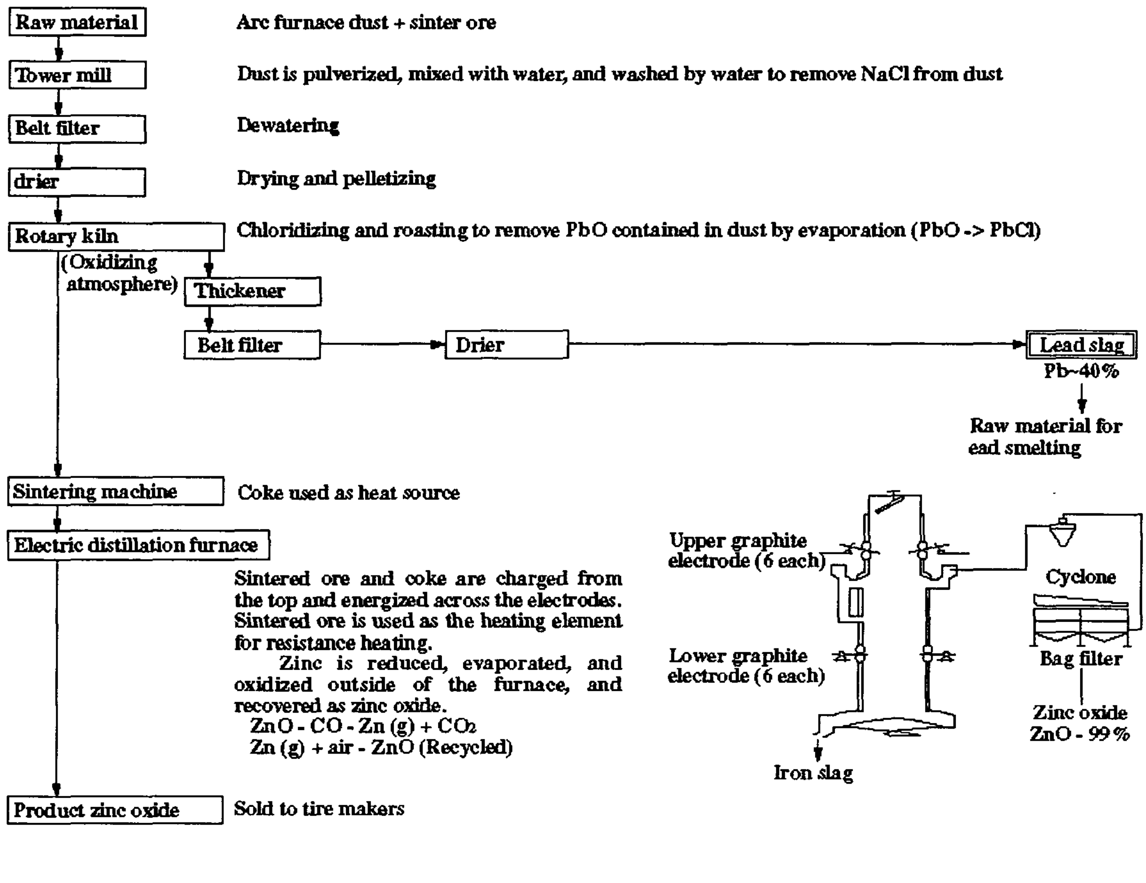


Fig. 8 Process flow of electric distillation method

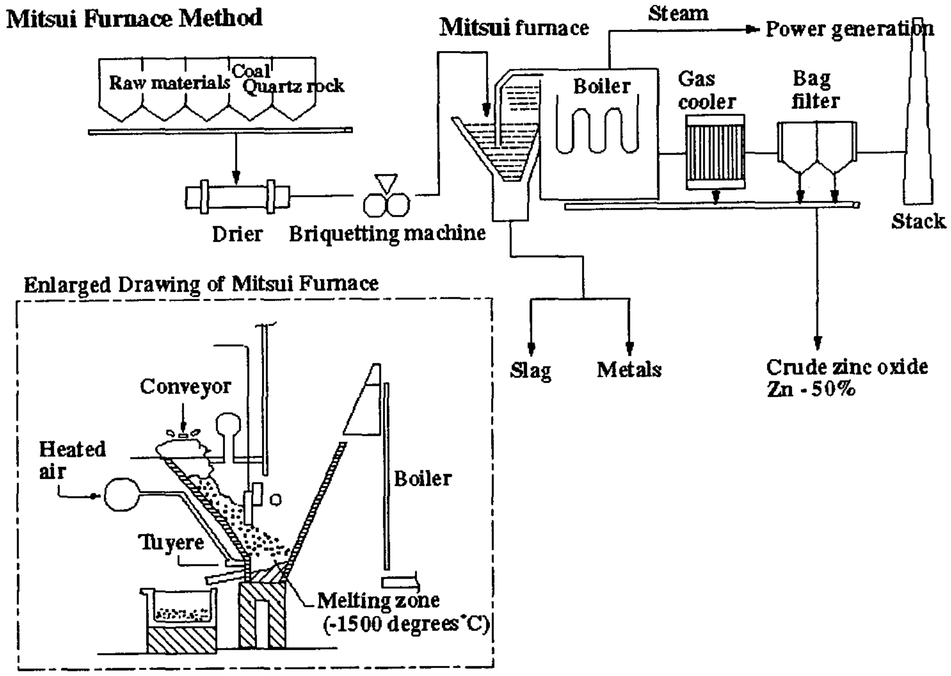
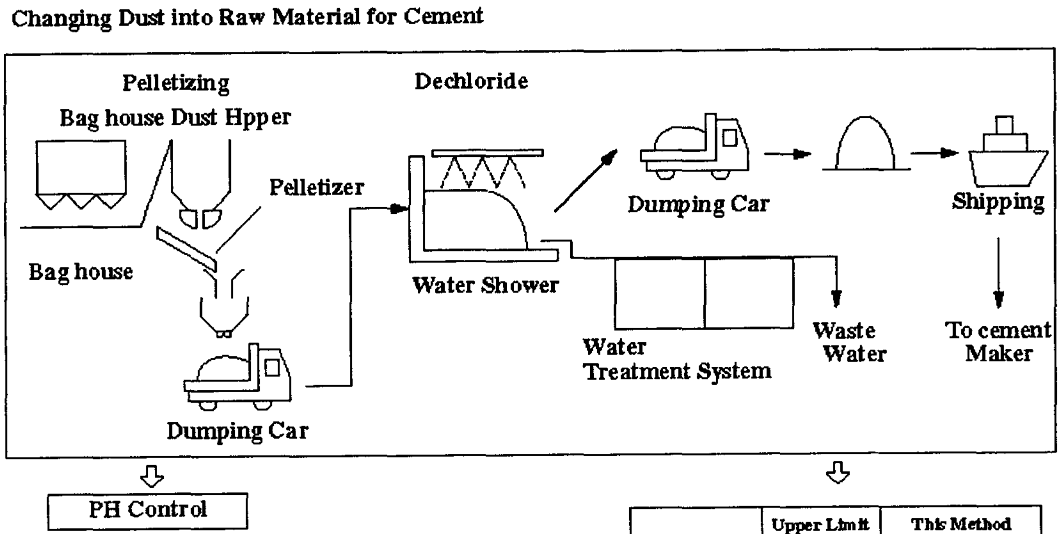


Fig. 9 Process flow of Mitsui furnace method



	Upper Limit	This Method
Chloride	0.1%	4% → 0.06% and under
Leaching LEAD	0.3mg/l	0.3mg/l and under

Fig. 10 Process flow of changing EAF dust into raw

2) Status of Recycling Zn Contained in EAF Dust

Dust is generated at a rate of 520,000 tons per year and the Zn content in the dust is estimated to be 20%. Therefore, Zn contained in the dust generated annually is 104,000 tons. On the other hand, 71% of 520,000 tons of dust generated per year, that is, 370,000 tons are routed to Zn recycling operations. When the Zn recovery rate is 70%, the total quantity of recycled Zn comes to 52,000 tons/year. Therefore, 50% of Zn contained in dust is currently being recycled. In other words, the remaining 50% is being lost in landfills, etc. As such, it is desirous that the industry develops measures to raise the recovery rate further in the future.

3) Problems and Issues Associated with EAF Dust Treatment

The problems associated with each method of EAF dust treatment are given in Table3.

The issues to be attended relative to EAF dust treatment are given in Table 4. New trends in EAF dust treatment to cope with these issues are described in the following section. [3]

Table 3 Problems Encountered in EAF Dust Treatment

Processing methods	Problem
Consignment to toll Zn recycling operations	1. High treatment costs (cost: 20,000 yen/t-dust) 2. A large amount of residue needed to be processed and disposed of as landfills 3. The problems of dioxins contained in dust
Landfills	1. High treatment costs (cost: 15,000 yen/t-dust) 2. Future restriction of landfill due to leaching of heavy metals and dioxins contained in dust 3. Depletion of landfill sites
Cement material	1. High treatment costs (cost: 20,000 yen/dust ton) 2. Future restriction of landfill due to leaching of heavy metals and dioxins contained in dust

Table 4 Issues to be attended

1. To reduce costs.
2. To resolve dioxin problems.
3. To develop methods to recycle Fe and zinc resources.
4. To develop on-site zinc recycling technologies, if possible.

4. New Trends in EAF Dust Treatment

1) DSM Process - Daido Steel

The outline of the DSM process developed by Daido Steel and in commercial operation at its Chita plant is shown in Fig. 16. The process uses a technology to produce slag by melting EAF dust and slag in the reduction period by burners that use C-grade heavy oil and oxygen. Slag thus produced is utilized as roadbed material.

In this method, slag is produced without reducing Fe_2O_3 contained in dust. Thus this method helps conserve energy otherwise required for reduction. Furthermore, since secondary dust is crude zinc oxide, it is used as an ISP material.[10]

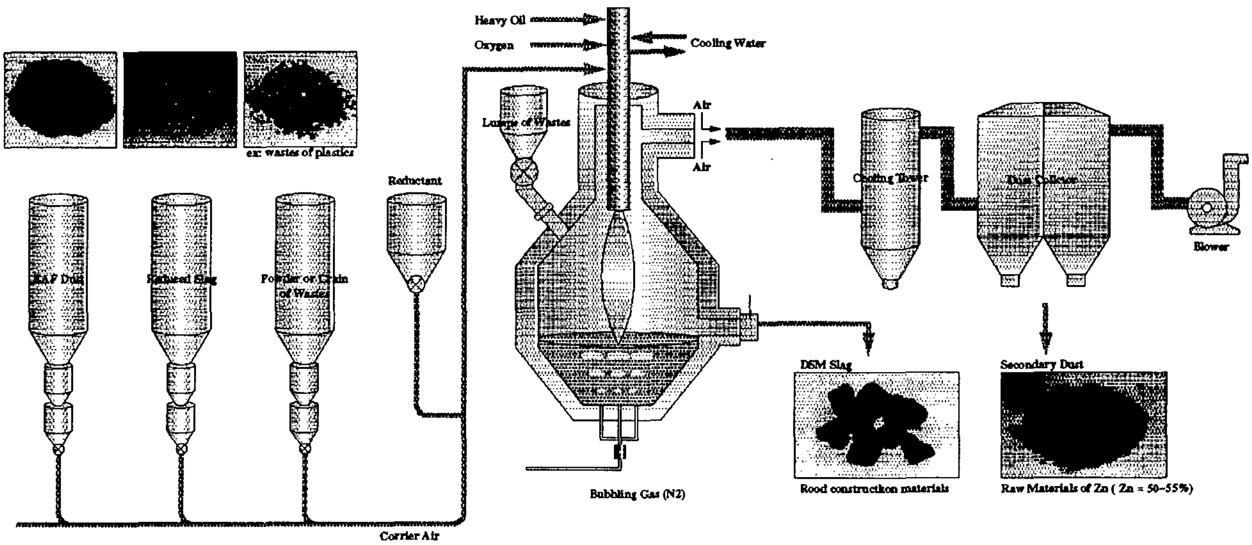


Fig. 11 General Outline of DSM Process

2) Z-Star Furnace - Kawasaki Steel

Fig. 12 schematically illustrates the Star furnace developed by Kawasaki Steel Corporation for processing SUS dust, to which a venturi scrubber, thickener, and centrifugal dewaterer are added for recycling crude zinc oxide.

Dust is blown in from the top of the 2-stage tuyeres on the coke-packed shaft furnace. Dust is reduced and melted in the shaft section to obtain slag and metals. The key lies in controlling the temperature in the upper shaft section so as to prevent Zn from precipitating. Zn is recovered as crude zinc oxide, and become an ISP material. A pilot plant in Kawasaki Steel's Mizushima Works is in commercial operation. [11]

3) VHR Process - Aichi Steel

The Flow of the vacuum heating reduction process under development by Aichi Steel is schematically illustrated in Fig. 13. Dust and the reducing agent, Fe or FeO, are mixed together, heated to 900 degrees C under vacuum to reduce zinc contained in dust to Fe. A pilot plant capable of processing dust at a rate of 700 tons/month has been constructed and is now in the development stage. [12]

4) EAF Injection of Dust + C (or Aluminum Dross)

In the framework of the New Steelmaking Forum, Usinor studied a process of injecting EAF dust mixed with C into an EAF for recycling. The results of the FS made on the process are given below. [13][14]

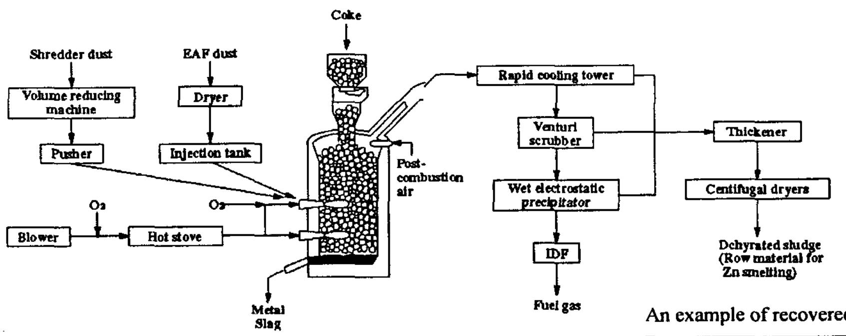
The components of dust are classified into two: the one that is distributed to dust and the other that is distributed to metals and slag. The conditions applied to the FS are given in Table 5. The resultant extent of thickening of zinc contained in dust is shown in Fig. 14. The drop in the quantity of dust is shown in Fig. 15.

Trial cost calculations were carried out. The downstream process is a zinc recycling process by the Waelz kiln method. Two types of process were examined: one is the process where the feed is melted mainly by electric power, and the other by coal. Three levels of initial zinc content (5%, 22.5%, and 35%) were compared as shown in Figs. 16 and 17.

The results clarified that the site specific conditions affect what are the optimum conditions.

Table 5 FS Conditions

Recycling dust : $Dn=Dn^{d}+Dn^{S}+Dn^{m}$
Dn^{d}(volatiles;Zn, Pb, Na, k, Cl, Cd, F)
Dn^{S}(Slag;Mg, Ca, Mn, Al)
Dn^{m}(metal;Fe, P, Cr, Mo, Cu, Sn, Ni)
Discharged dust
$Dn^{m}+1=D^{s}+Dn^{d}+\alpha(Dn^{S}+Dn^{m})$
Dust originally discharged
Alpha = Direct fly off



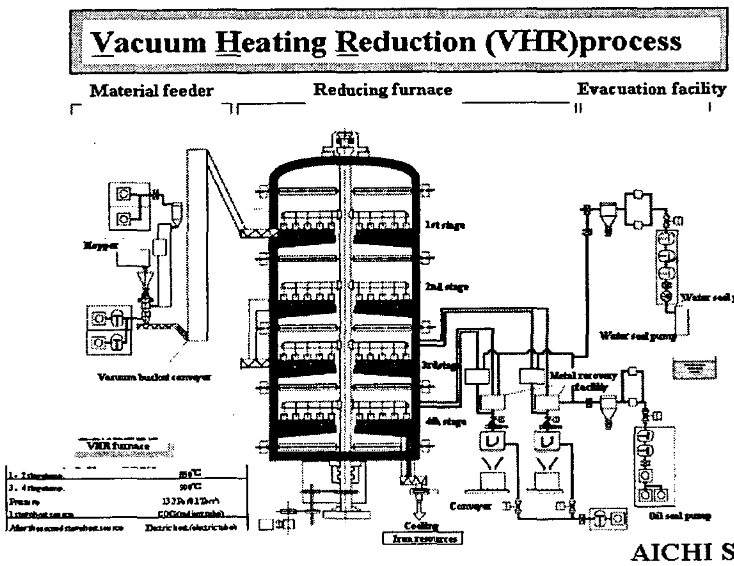
An example of produced metal and slag composition

Metal		Slag	
C	4.2	CaO	37
Si	2.5	SiO_2	36
Mn	1.7	Al2O3	15
P	0.28	MgO	6
S	0.09	Fe	1.5
Zn	0.005	Zn	0.01
Pb	0.001	Pb	0.001
Cu	0.52	Cu	0.01
Cr	0.63	Cr	0.12

An example of recovered composition

T.Zn	T.Fe	Pb	C	SiO_2	Al_2O_3	CaO	Dioxins
60.0	1.71	6.2	2.27	2.98	1.14	1.75	0.0001ng-TE Q/g

Fig. 12. Equipment Flow of Z-Star Furnace and Typical Product Analysis



AICHI STEEL

Fig. 13 Equipment Flow of Vacuum Heating Reduction Process

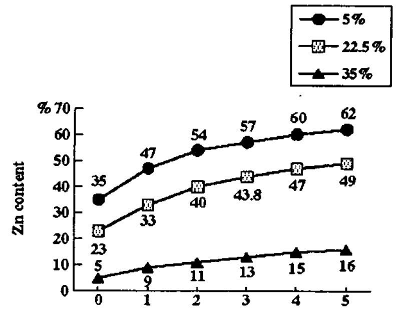


Fig. 14 Recycling Frequency and Zinc Content

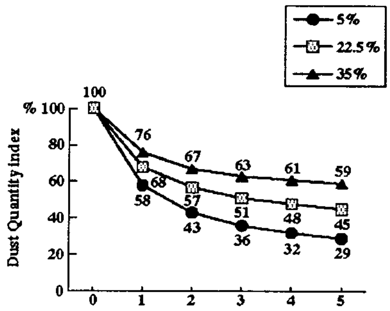


Fig. 15 Recycling Frequency and Dust Quantity

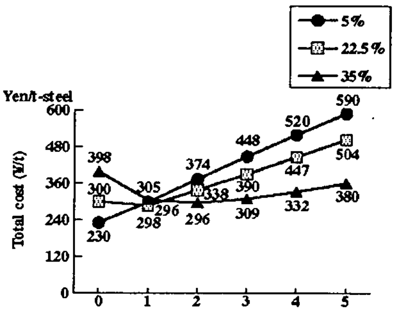


Fig. 16 Recycling Frequency and Cost (Centered on melting by electric power)

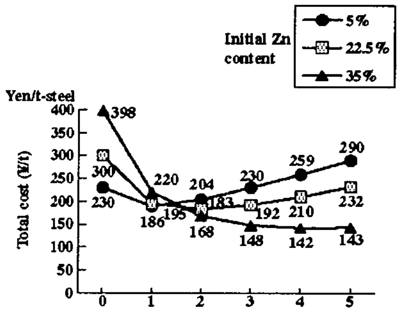


Fig. 17 Recycling Frequency and Cost (Centered on melting by Coal)

While simulations shown above were carried out assuming a mixture with C, simulations were likewise carried out assuming a mixture with aluminum dross. It was found that there is practically no basic difference with the FS results described above.

5) EAF Injection of Dust + Aluminum Dross and Decomposition of Dioxins

Dust and aluminum dross are mixed together and injected into the EAF, and the behavior of dioxins was investigated. The results are given in Table 6. The mass balance of chlorine is given in Table 7.[15]

Table 6 Reduction Rate of Dioxins

	Special steel		Carbon steel	
	Bucket charging method	Injection method	Bucket charging method	Injection method
Quantity of dioxins contained in dust	1.0ng-TEG/g ↓ 0.38	1.0ng-TEG/g ↓ 0.38	2.0ng-TEG/g ↓ 0.38	2.0ng-TEG/g ↓ 0.38
Reduction rate	62%	60%	35%	53%

↓

EAF injection recycling of dust reduces dioxins by 50% or more per cycle.

Table 7 Mass Balance of Chlorine

		Conventional method	Bucket-charging method	Injection method
Special steel	Slag	6.9	8.9	8.7
	Metals	0	0	0
	Off gas	0.5	0.5	1.1
	Dust	92.6	90.8	90.2
Carbon steel	Slag	1.1	1.2	1.6
	Metals	0	0	0
	Off gas	4.7	9.3	7.6
	Dust	94.2	89.4	90.8

↓

Most of the chlorine is distributed to dust, but a slight amount is also distributed to slag and off gas.
When dust injection is carried out, distribution to slag and off gas is caused to increase.

EAF dust injection recycling reduces dioxins by 50% or more in one cycle. While most of the chlorine is distributed to dust, a slight amount is also distributed to slag and off gas. When dust is injected to the EAF, the distribution to slag and off gas is caused to increase.

6) JRCM Process - Development of Energy-Saving Metallic Dust Recycling Technology -

Consigned from NEDO, a process to directly recycle iron and zinc from EAF off gas is under development at

JRCM (hereafter referred to as the JRCM process). The process image is illustrated in Fig. 18. [16]

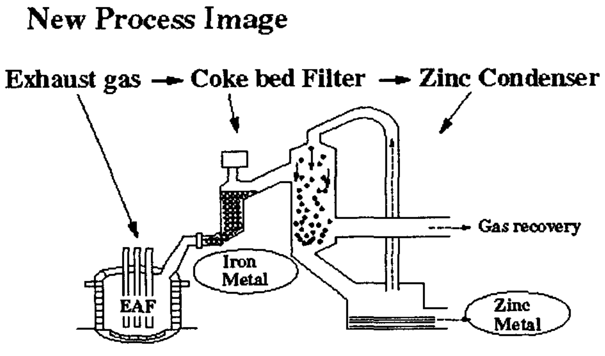


Fig. 18 Development Image Diagram of JRCM Process

The EAF is completely sealed in this process. Off gas and dust were sampled from within the furnace, and analyzed. The results showed that the off-gas temperature reached 1100 degrees C or higher, the CO/CO_2 ratio was 2 or more, and the quantity of off gas was 100 Nm3/t/hr.
Fe is present in the EAF as metal Fe or FeO; Zn as Zn vapor. The particle size was found to be in the order of less than 1 μm.
At present, a small-scale pilot plant (100 Nm3/hr, or equivalent to an 1 t/hr EAF) was installed in Aichi Steel's Chita plant, and is being used to prove the viability of this process.
The process is regarded as a "Dream Process" that achieves zero wastes. We hope to be successful in developing this unique technology that originates in Japan and would be applicable throughout the world.

5. Conclusion

1) The essential issue associated with the EAF process is to develop low-cost zinc recycling technology.
The DSM and Z-Star furnaces have entered into commercial operation. The VHR furnace is under development. The industries concerned place high expectations in the success of such new endeavors.
2) The JRCM process under development at JRCM is regarded as a "Dream Process" that realizes no generation of dust. We hope we will be successful in developing this new technology that would be applicable throughout the world.

References

[1] Survey of Current Status and Future Trends in Japan and Overseas in respect to EAF Dust Treatment: March, 1996, Denrogyo Kozo Kaizen Sokushin Kyokai
[2] The Study of Fundamental Technologies for Environmentally-friendly Recycling of Metallic Materials, Fiscal 1994; Report on the Results of Overall Basic Investigative Studies, March 1995, Chikyu Kankyo Sangyo Gijutsu Kenkyu Kiko
[3] Sasamoto, H., Aichi Steel Corp. ;Present situation and problem of iron making industry dust treatment; CAMP-ISIJ Vol. 10(1997)
[4] Electric Arc Furnace Dust; Disposal, Recycle, and Recovering: May 1985, The EPRT center for materials production
[5] Birat et al. ; Some Means to Reduce Emissions and Improve the Recovery of Electric Arc Furnace Dust by Controlling the Formation Mechanisms gases; September 1999, REWAS'99, Vol. II
[6] Yasui, M., Aichi Steel Corporation, et. al. ;Development of direct separation and reclamation process of iron and zinc from EAF gases; December 2000, ATS,p.214
[7] Kochihira, G.; Dust recycling technology by rotary kiln at Kashima Steel Works of Sumitomo Metals; March 1997, CAMP-ISIJ Vol.10(1997)
[8] Inoue, K. ;Technology of electrothermic funace process for EAF dust treatment; March 1997, CAMP-ISIJ Vol.10(1997)
[9] Miyawaki, A.; Decholorin process of EAF dust; March 1997, CAMP-ISIJ Vol.10(1997)
[10] Ozawa, M., et. al.; Development of A New Dust and Slag Treatment Technology (Construction and operation of DSM Process); Aril, 1999, DAIDO Technology, Vol. 70
[11] Suito, M., et al.; Construction and Operations of Advanced Dust Smelting Furnace (Z-STAR) - Recovery of Valuable Minerals and Fuel Gas from EAF or Shredder Dust; December 2000, Kawatsaki seitetsu Giho 32
[12] Sasamoto, H. of Aichi Steel Corp. ;Development of Recycling Process for Electric Arc Furnace Dust; 1997, Vol.138 NO.5/203, IE Review, Japanese Industrial Engineering Association
[13] The Study of Fundamental Technologies for Environmentally-friendly Recycling of Metallic Materials, Fiscal 1994; Report on the Results of Overall Element Process Studies, March 1995, The Japan Research and Development Center for Metals

[14] Sasamoto, H., Aichi Steel Corp.; Feasibility study of dust direct recycle of Electric Arc Furnace; CAMP-ISIJ, Vol.13(2000)-730
[15] Yamada, Y., Aichi Steel Corp.;Dioxin Control Technology by Dust Direct Recycle to Electric Arc Furnace, CAMP-ISIJ Vol. 13(2000)-995
[16] Yasui, M.;Concept of the process and characteristics of high temperature exhaust gas from EAF; CAMP-ISIJ Vol.14(2000)-151