EAF DUST TREATMENT FOR HIGH METAL RECOVERY

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.

Rotary kiln process is the main stream of present EAF dust treatment, but they still have the weakness of iron-including clinker disposal. Smelting reduction process has the advantages of almost complete metal recovery and detoxification of the dust, but it was not economically competitive because of higher energy cost. But the situation is changing with the increase of metal prices and severe environmental regulation.

KATEC R&D Corporation in Taiwan and JP Steel Plantech in Japan have resolved this problem by developing a new electric smelting reduction furnace (ESRF) process.

The first ESRF plant was constructed in Taiwan and started commercial operation in September 2010. 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 generated dust accounts for 2 % of the produced steel. 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. EAF dust treatment is the process to recover valuable metals from the dust and to make the residue harmless for disposal. During the dust treatment, 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 plants for EAF dust treatment.

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 melting 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 at TaoYuan Province in Taiwan and started test-operation in December 2009 followed by commercial operation from September 2010.

2. EAF dust from steel industry

Table 1 shows an example of EAF dust composition. The main components are 30 % zinc, 20 % iron, and 5 % 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.

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

Of the 500,000 ton/y of EAF dust generated in Japan, about 60 % is processed by rotary kilns to recover zinc, but 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 for all of Japan. Another problem is the shortage of the space for landfill and disposal.

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.

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 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

3. EAF dust treatment process

The existing dust treatment plants are classified to two groups, namely 1) solid reduction process and 2) smelting reduction process. Both processes reduce zinc oxide in the dust to zinc vapor to separate it from the residue. Solid reduction process does not melt the iron oxide, and partially reduce it to FeO. On the other hand, smelting reduction process melts down and reduces almost all the metal oxides in the dust.

Solid reduction process includes rotary kiln, rotary hearth furnace, and multi-stage hearth furnace. Smelting reduction processes are, for example, EMPF by ELKEM, PIZO by Heritage Technology, Tetronics plasma furnace, our ESRF, and others. Solid reduction process uses combustion energy, which is cheaper than electrical energy. But large volume of exhaust gas causes dust carry-over and decrease in ZnO content in the recovered material (crude ZnO). Relatively lower reaction temperature makes it difficult to reduce iron oxide completely and to remove heavy metals at high rate from slag or clinker. The remaining FeO and heavy metals in the clinker is the common problem at many of the solid reduction processes.

The rotary kiln process, famous as Waelz process, is the most popular in this category and tens of units are working in the world. As it is difficult to operate small size kiln, the kiln plant should be constructed as a large scale to collect the dust from several arc furnace plants. It is not an easy business to organize EAF steel companies as clients. Rotary hearth furnace has been becoming popular for blast furnace dust and converter dust, and only one RHF for exclusively EAF dust use was constructed in Japan. But operation is reported not so easy for its high chlorine and zinc contents, and much generated clinker is the next problem.

Smelting reduction process uses electrical energy to heat and reduce metallic oxides in the EAF dust. With the very high temperature by electricity, it melts down all the materials in the dust, which makes it possible to recover iron as metallic Fe and to realize very high separating rate of heavy metals from the slag. As no fossil fuel is used, exhaust gas volume is smaller to realize low dust carry-over rate. Therefore, ZnO percentage in the crude ZnO is higher than solid reaction process. Fig.1 shows the concept of smelting reduction process.

Many smelting reduction processes were tested and constructed in these 30 years, but most of them were shut down. The reason is the higher energy cost and lower price of recovered metals. But the situation is changing. Metal prices are getting higher, and environmental regulation for the disposal of dust, slag, and clinker has been strengthened. Comparing to the prices of 5 year before, zinc price became 2.5 times higher and iron source price 4 times higher. Another characteristic of smelting reduction process is that it can be designed as a very compact unit. One unit for each arc furnace is suited, and it is easier to construct it within the arc furnace plant. In that case, molten pig iron with high carbon content (4%) is welcomed by EAF for energy saving, not only for metal recovery.

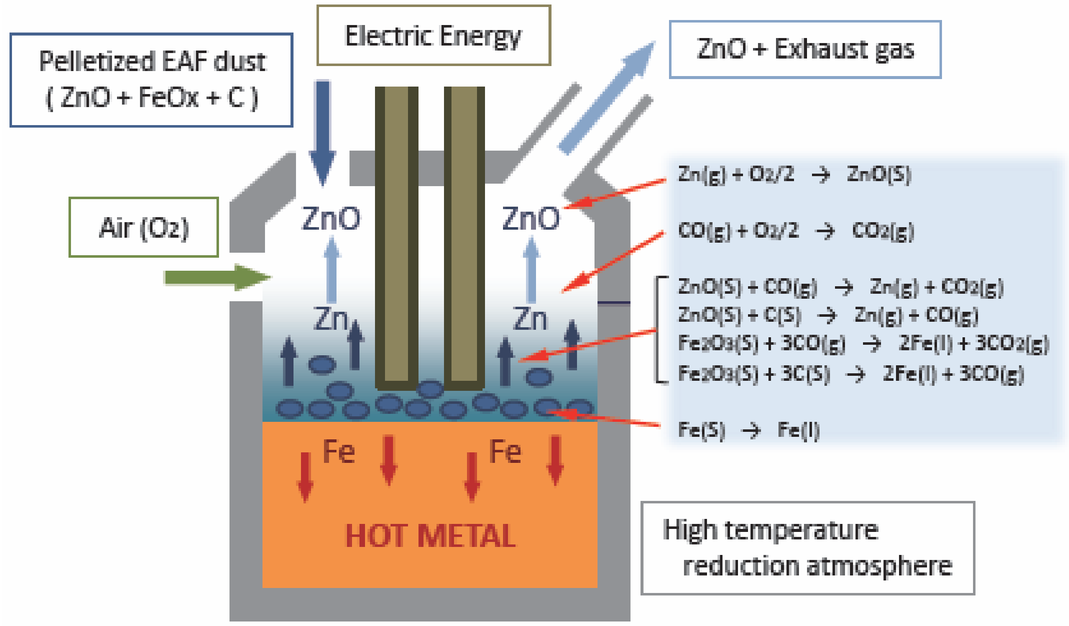

Fig.1 Concept of smelting reduction process

4. Metal recovery and wastes from EAF dust

With the upgrading of living standard, consumption of zinc-coated steel sheet has been increasing. With the increase in zinc in the scrap, zinc percentage in the EAF dust is increasing. Natural resources of zinc are not so abundant, and the recovery from the wastes is becoming important. Also recovery of iron from the dust should be considered with the price increase of iron resources. For this reason, superiority of smelting reduction process should be reconsidered. Fig. 2 and Fig.3 show the diagram of metal recycle by conventional (solid reduction) process and advanced (smelting reduction) process. Heavy metals in the clinker from conventional process prohibit the simple landfill, therefore, the process is said to be still “not completed”. On the contrary, smelting reduction process recovers most of the valuable metals and generates harmless slag, which can be used as aggregate. The process can be said as a “completed zero emission”.

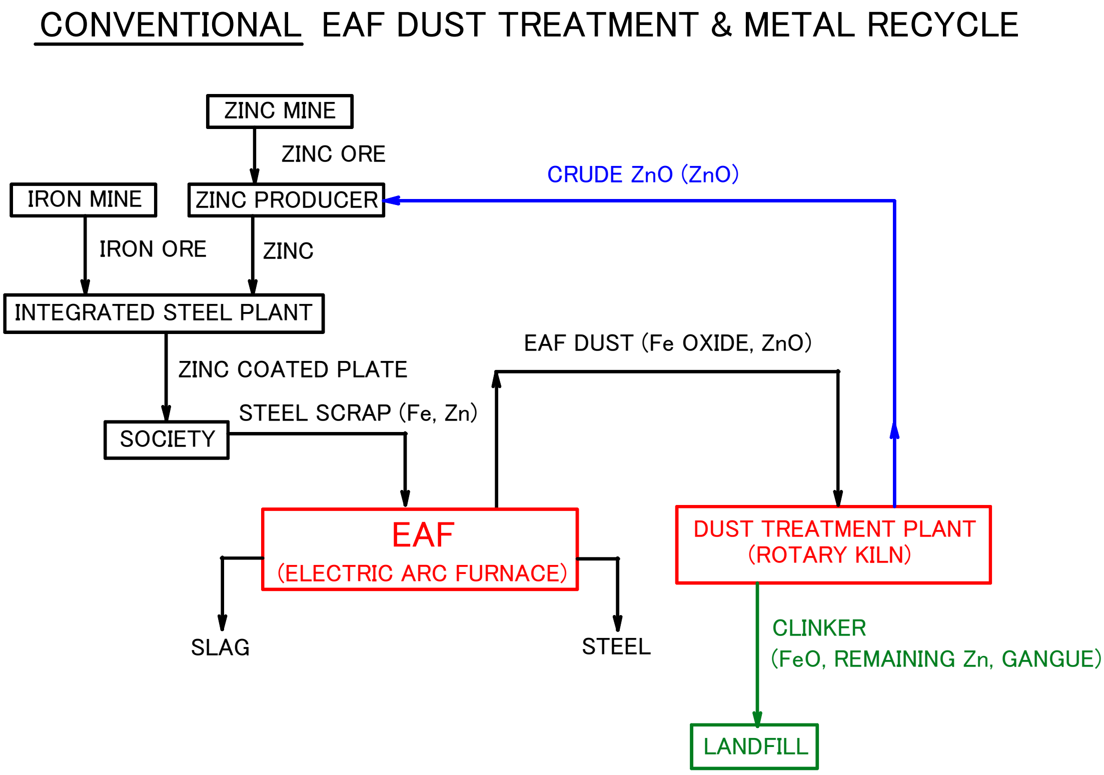

Fig.2 Conventional metal recycle from EAF dust

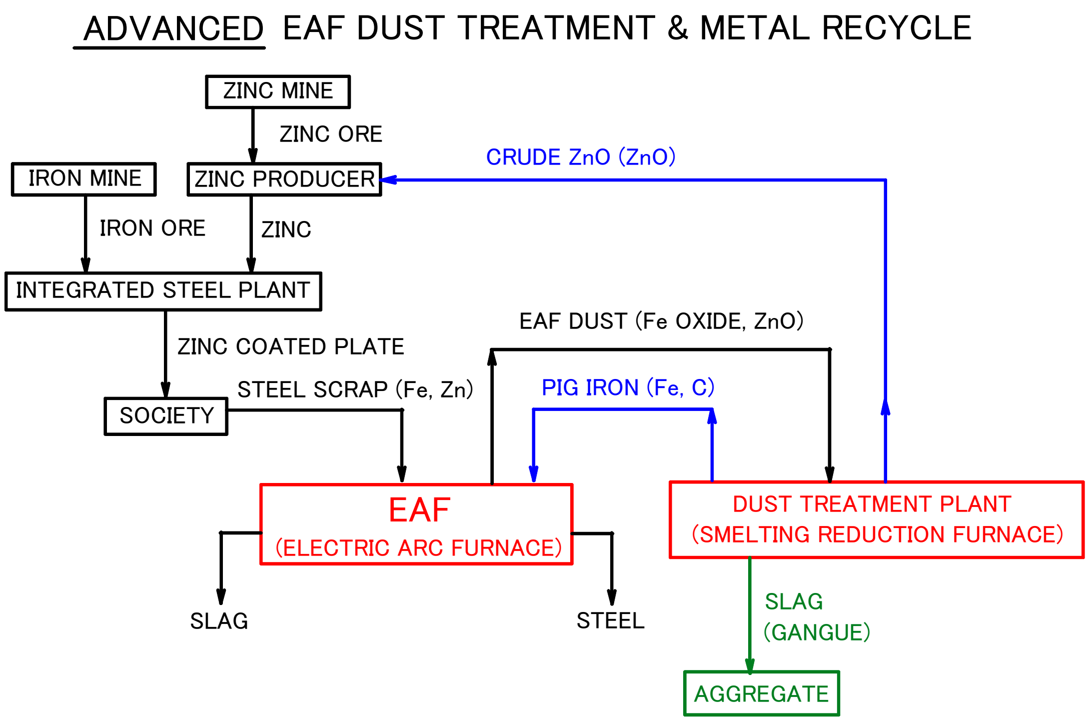

Fig.3 Advanced metal recycle from EAF dust

5. Outline and advantages of ESRF process

ESRF was developed and constructed under the cooperation of KATEC R&D Corporation (Taiwan) and JP Steel Plantech Co.(Japan). The concept of the

process is conventional (Fig.1). Agglomerated EAF dust is charged into the melting furnace with coke and limestone. However, during the design stage of the new plant, careful attention was paid to the configuration of the exhaust gas cooling and de-dusting devices. Fig. 4 shows the outline of the gas treatment portion. Carbon monoxide and zinc vapor in the gas are oxidized in the ESRF and combustion chamber. The combustion chamber is a simple vertical cylinder with water-cooled wall. The vertical water-cooled wall avoids the adhesion of softened materials in the dust.
The dimension of the chamber is decided to satisfy the design guideline of the incinerator, namely at least 2 seconds at a temperature above 850 ºC. Hot gas temperature in the ESRF is about 1250 ºC, which completely decomposes dioxins in the dust. Particles of iron oxides and carbon settle at the bottom of combustion chamber and recycled to the ESRF. Particles of ZnO and chlorides, which are very fine, do not settle in the combustion chamber but carried to the multi-tube gas cooler. Gas temperature in the gas cooler is designed to solidify the chlorides on the surface of vertical tubes, therefore the adhering chlorides can be easily and automatically removed.

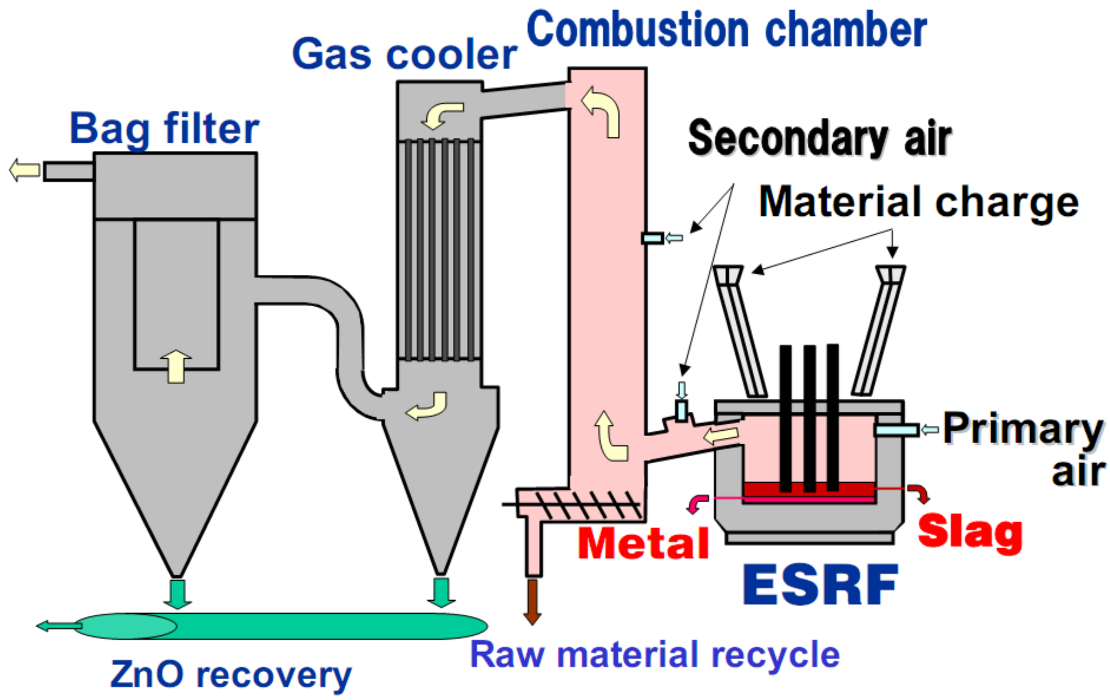

Fig.4 Concept of ESRF exhaust gas line

300-350 ºC exhaust gas at the gas cooler outlet is cooled down to about 150 ºC by dilution air to match the design temperature of bag filter. All dry-process, which does not use water spray, is employed because of the high moisture-absorption property of crude ZnO.
Furnace body is not inclined for tapping as conventional EAF is. There are three tapping holes on the sidewall for metal, slag, and full material tapping respectively. Fig.5 shows the furnace body and troughs during construction.

Fig.5 Furnace body and tapping troughs

Table 3 shows the ingredients in recovered materials. High-carbon pig iron is returned to arc furnace steel mills. Slag is cooled down slowly in the slag pot to generate crystallized structure. In addition to this crystalline structure, very low leaching values of such heavy metals as Zn, Pb, and Cd allow this slag to be used for not only simple landfill but 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.

Table 4 is the air pollution measurement data, and Table 5 is the slag leaching data of ESRF plant in Taiwan. All the figures are extremely lower than the regulation values. It can be said that the ESRF process is the environmentally acceptable advanced process.

Table 4 Air pollution data at ESRF plant

DATE	Particle (mg/m3N)	SOx (ppm)	NOx (ppm)	HCl (ppm)	Pb (mg/m3N)	Cd (mg/m3N)	Hg (mg/m3N)	Dioxin (ng-TEQ/m3N)
Regulation	55	650	500	60	10	1	0.00352	0.4
2010/2/26	1	1.78	2.01	8				
2010/3/8					0.0198	0.00034	0.00026	
2010/4/20								0.007
2010/5/27	ND	1.73	2.26	ND	0.0085	0.00009	0.00009	0.011
2010/11/3	ND	1.15	ND					
2011/1/19	ND	1.12	1.92					0.004
2011/4/12	ND	1.65	2.23					
2011/7/13	ND	3.19	ND					

Table 5 Slag leaching data at ESRF plant

DATE	As (mg/L)	Hg (mg/L)	Se (mg/L)	Cr+6 (mg/L)	Cr (mg/L)	Cd (mg/L)	Pb (mg/L)
Regulation	5	0.2		2.5	5	1	5
2010/1/20	0.0012	ND	0.0083	ND	0.014	0.008	0.29

Table 6 shows sample data of the recovery rate of valuables and unit consumption for economic evaluation. Recovery rates also fluctuate with the variation of ingredients in the EAF dust. 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, the selling price is estimated to be 25 % of the LME price of zinc ingots. Although many arc furnace companies are paying disposal fee of EAF dust at present, this fee can be saved when ESRF plant is adopted.

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

Fig. 6 and Fig. 7 show the recovered pig iron and crude ZnO. Selling prices of these are about 550 US$/ton for pig iron and 580 US$/ton for crude ZnO.

Fig.6 Recovered pig iron

Fig.7 Recovered crude ZnO

6. Profitability

Feasibility study of 2 ton/h ESRF plant was done to evaluate its profitability. 2 ton/h is the minimum practical plant size, and 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 ton/y. The study was done for two cases 1) in developed countries, where dust treatment fee 250 US$/ton becomes unnecessary with the adoption of ESRF, and 2) in developing countries, where dust treatment fee is zero at present. We could get the conclusion that in both cases ESRF is profitable. In the case of 2), cheaper electricity price and lower labor cost contribute to the profitability improvement. But dust treatment process should not be discussed from the simple economical viewpoint, the environmental aspect is the important point to consider it. ESRF remarkably contributes to reduce air pollution substances and toxic solid wastes.

7. Conclusions

Characteristics and advantages of ESRF process is summarized as below:

(1) Smaller exhaust gas volume by electrical heating realizes less carry-over of charged dust and higher ZnO content in crude ZnO.

(2) Most of the Fe in the dust is recovered as molten pig iron, which is a useful iron and energy source for EAF.

(3) High gas temperature of over 1250 ºC completely decomposes dioxins in the charge dust.

(4) No hazardous materials remain in the slag, and the leaching values of heavy metals in the slag is very low. Slowly cooled slag generates crystallized structure, and it can be used for many purposes.

(5) Compact equipment size matches to the on-site plant in the arc furnace factory.

Increase in recovered metal prices and increasingly severe environmental regulation have been requiring to reevaluate the EAF dust treatment processes. Smelting reduction process was once abandoned, but it is again revised upward with the recent situation changes. New ESRF process is expected to meet the requirements from the society.