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## Recycling of Wastes

### Activities of the Total Energy and Materials Control System investigation committee in the Japan research and development center for metals (Review)

*T.NAKAMURA et al.*

Suppression of the explosion of the world population and the surprising increase of waste and emissions are major targets confronting mankind in the next century. Metal industries have consumed a tremendous amount of energy and discharged a large quantity of $CO_2$ and solid waste, although the metals they have produced have supported a high quality of life. Recycling and waste minimization are key words for sustainable development in a highly industrialized society.

The Total Energy and Materials Control System (TEMCOS) investigation committee began in 1997 in the Japan Research and Development Center for Metals (JRCM) to address these problems. The goal of TEMCOS is the achievement of zero waste and energy minimization to make a strong inter-process linkage between different industries. Activities of the committee are described here.

(cf. *ISIJ Int.*, **40** (2000), 212)

### Environmental aspects and recycling of filter dusts by direct injection or use of agglomerates in shaft furnaces

*H.W.GUDENAU et al.*

In the last decades the recycling of filter dusts of the iron and steel industry has become more and more important due to environmental as well as economical reasons. Beside of so-called end of pipe technologies, processes are required which ensure an efficient waste management with regard to productivity and profitability of steelworks. In this context the development of integrated systems is necessary to recover and to recycle valuable components.

This paper describes possible techniques for an integrated treatment of filter dusts. On the one hand the injection of filter dusts in shaft furnaces is studied. For the trials a laboratory injection rig is used which simulates the injection of solids under conditions similar to the blast furnace. On the other hand the use of briquettes and pellets with embedded carbon in a shaft furnace is investigated by means of laboratory and industrial pilot trials.

The results will be described and discussed with regard to the reduction behaviour of different coal-dust-mixtures.

(cf. *ISIJ Int.*, **40** (2000), 218)

### The strength and the high temperature behaviors of self-reducing pellets containing EAF dust

*M.C.MANTOVANI et al.*

The objective of this work was to study the cold and hot behaviors, that is, cold compressive strength, decrepitation, swelling, compressive strength after heating and efficiency of zinc removal of self-reducing pellets containing coal fines and EAF dust. Pellets with 3 and 5 wt% Portland cement, 12 wt% $CaCO_3$ and without additive were produced. The effect of binder addition on the cold compressive strength was studied during 28 days. For the study of the high temperature behavior, pellets were submitted to thermal cycles with different heating intensities. The best results of cold compressive strength were obtained with 5 and 3 wt% Portland cement due to hydration of components that are contained in this binder. Pellets with Portland cement (3 and 5 wt%), after drying, did not present decrepitation, showing a correlation between the decrepitation, moisture content and mechanical strength of the pellet. Abnormal swelling was observed in pellets submitted to the thermal cycle with lower heating intensity. Such abnormal swelling was due to the growth of whiskers, and as consequence, it was recorded a maximum swelling (higher than 30%). With the gasification of carbon promoted by the release of $H_2O_{(g)}$ and $CO_{2(g)}$ from the Portland cement and $CaCO_3$, it was possible to obtain a higher zinc removal as compared to the value obtained with pellets without additives, mainly at 1 124°C.

(cf. *ISIJ Int.*, **40** (2000), 224)

### Smelting reduction process with a coke packed bed for steelmaking dust recycling

*Y.HARA et al.*

A new smelting reduction process with a coke packed bed has been developed for iron, chromium, and nickel recovery from BOF dust, and for simultaneous recovery of zinc and iron from the electric arc furnace dust. The process is characterized by direct use of fine raw materials without agglomeration, recovery of almost the whole amount of zinc and lead, and no emission of secondary waste, compared with the conventional recovery methods.

The commercial plant for BOF dust recycling has been operating stably with a metal production capacity of 200 tons per day. The blast condition is controlled so that the temperature at the lower tuyere level becomes higher than 1 550°C, which is the condition required for the smelting reduction of chromium and iron oxides.

The validity of the process idea for EAF dust recycling was confirmed and the key technologies were established through the pilot plant tests with a scale of 10 tons per day. It was found that zinc oxide was almost completely reduced and vaporized at the thermal state of the furnace, $T_{melt} \geqq 1\,550$°C, which allowed chromium and iron to be reduced. The control of the temperature and $CO_2/CO$ ratio of the top gas was important for the prevention of zinc adhesion on the wall of the furnace top.

(cf. *ISIJ Int.*, **40** (2000), 231)

### Coke breeze-less sintering of BOF dust and its capability of dezincing

*M.NAKANO et al.*

In order to promote recycling of basic oxygen furnace (BOF) dust, sintering of the dust without coke breeze (fuel) has been researched by pot test method and the possibility of dezincing during the sintering has been evaluated.

Typical BOF dust, containing about 20% of metallic iron (M.Fe), is agglomerated without fuel and dezinced by about 50% during sintering. The agglomeration is caused by heat generation due to oxidation of the metallic iron. The dezincing takes place by the reaction: $ZnO + M.Fe \rightarrow Zn(gas) + FeO$ at elevated temperature. Secondary dust emitted during sintering mainly consisted of ZnO containing 40 to 50% of zinc. The ratio of dezincing is improved by blast furnace (BF) dust addition and up-draft sintering method. The carbon in BF dust produces metallic iron and CO gas from "FeO" melt, then they accelerate ZnO reduction. The up-drafting makes a melt pool in the lower layer, where the melt remains longer at high temperature, resulting in increase in the ratio of dezincing.

(cf. *ISIJ Int.*, **40** (2000), 238)

## Gasification and Smelting of Wastes

### Development of waste plastics injection process in blast furnace

*M.ASANUMA et al.*

At Keihin No. 1 Blast Furnace, waste plastics recycling system was installed in Oct. 1996. Before the installation of that system, the behavior of waste plastics injected into the blast furnace has been studied with the raceway hot model and the commercial blast furnace so as to investigate the possibility of effective waste plastics utilization in the blast furnace. From the observation of plastics particle injected into the raceway of blast furnace, it was estimated that combustibility of coarse plastics was much different from that of pulverized coal. The combustion point of coarse plastics located to deep domain in raceway compared with that of pulverized coal. Although $C_1$–$C_4$ hydrocarbons due to the decomposition of plastics was detected in in-furnace, the decomposition products of plastics in the blast furnace top gas and dust were the same as that of pulverized coal injection. The preparation method of plastics had an influence on the combustion and gasification behavior in the raceway. The coarse plastics gave high combustion and gasification efficiency compared with fine plastics and pulverized coal, and $CO_2$ gasification rate of unburnt char derived from waste plastics was much higher than that of pulverized coal. Thus, it was concluded that coarse waste plastics could be effectively utilized as a reducing agent in the blast furnace. On the basis of above results, the waste plastics recycling system was designed.

(cf. *ISIJ Int.*, **40** (2000), 244)

### Shredder dust recycling with direct melting process

*H.SHIBAIKE et al.*

The shredder dust contains a large amount of incombustibles and some toxic ingredients. Therefore, the shredder dust is very difficult to be reduced in its volume and made harmless in the treatment by using the conventional incineration technology. In order to solve this problem, the authors suggested the method to treat the shredder dust by the direct melting process of the coke-bed type shaft furnace. The treatment of municipal solid waste (MSW) by the process has been proven to be effective in many

commercial plants. In this study, the characteristics of the shredder dust compared with those of MSW were investigated. Some experiments on melting treatment of the shredder dust were carried out at the direct melting experimental plant. As a result, the shredder dust was efficiently and stably treated by using the direct melting technology which utilized a multi-stage blasting. Also the content of dioxins in the exhaust gas was below 0.1 ng-TEQ/Nm$^3$ and the gas was purified with the conventional pollution control technology. The slag and metal produced from the shredder dust were reusable in the same way as those from MSW and the volume reduction of the waste was remarkably realized by the application of the direct melting technology.

(cf. *ISIJ Int.*, **40** (2000), 252)

### Gasification and smelting system using oxygen blowing for municipal waste

*T.YAMAMOTO et al.*

A new type of waste gasification and smelting system, which uses iron-making and steel-making technologies, has been developed. It is a coke-free process and can produce dioxin-free and high-calorie purified gas and high-quality slag. This report describes the results of a basic concept function test by a bench furnace with the capacity of 2 tons/day based on municipal waste, as well as the operation results of a 20 ton/day demonstration plant.

As a result of maintaining the furnace gas at 1 343 K and cooling the gas rapidly, the concentration of dioxins at the exit of chimney was less than 0.01 ng-TEQ/Nm$^3$. The molten slag continuously produced by this system contained very little iron oxides, because iron was removed in advance and the lower part of the furnace was maintained in high-temperature reduction atmosphere. The ratio of heavy metals moving into slag is very small because the temperature is high and heavy metals such as Hg, As, Pb, Cd, Zn and so on are volatile in the furnace. As the absolute quantity of heavy metals contained in the slag is little, the results of the heavy metal leaching test of the slag satisfies the standard value of the test.

(cf. *ISIJ Int.*, **40** (2000), 260)

## Hazardous Wastes

### Remediation technologies of ash and soil contaminated by dioxins and relating hazardous compounds (Review)

*S.HARJANTO et al.*

In recent years, contamination of toxic organic compounds such as polychlorinated dibenzo-*p*-dioxins and dibenzofurans (PCDD/Fs), and polychlorinated biphenyls (PCBs) into combustion/incineration ash and soil has become a serious environmental problem. Many efforts have been made to develop efficient remediation technologies which remove, neutralize and/or decompose such compounds in solid materials. The remediation technologies may be classified into the following three types: biological (bioremediation), physical/chemical and thermal remediations. The present paper introduces several remediation technologies for ash and soil and discusses their present states of development.

(cf. *ISIJ Int.*, **40** (2000), 266)

### Proposal of treatment for hazardous wastes using the highly concentrated radiation from torch plasma

*T.IWAO et al.*

The plasma torch that can usually reduce the waste and dissolve the iron and so on has very useful characteristics. It is a kind of the stabilized arc plasma that can be easily controlled. It has been examined considering the influences or various parameters, such as the current, the gas flow-rate and the plasma length.

In this paper, we measured the radiation power emitted from the Ar plasma torch. The radiation power increased in proportion to the 1.8–1.9th power of the current at 1, 2 cm of appearance plasma length. And it increased in proportion to the 0.2–0.4th power of the gas-flow rate between 4–20 Nl/min.

Then, we measured the temperature of the radiation spot collected by reflectors using the thermocouple. It increased in proportion to the 2.0–2.1th power of the current at 1 cm and 2 cm in the plasma length. Moreover, the total temperature is calculated as 16 860 K in a torus model.

We proposed the treatment for the hazardous wastes using the highly intense radiation of Ar torch plasma collected by reflectors and concentrated by the lens. And, we proposed the plasma treatment of the high temperature and radiation power for the hazardous wastes by using the plasma torch.

The plasma torch ordinary has the high temperature and plenty of radiation power. Therefore, when both of the characteristics are combined usefully, we can get the many more benefits; the in-put power is used little, hazardous wastes are treated by the high temperature and hazardous gas from the wastes is treated by the radiation power.

(cf. *ISIJ Int.*, **40** (2000), 275)

### Primary application of the "In-Bed-deNOx" process using Ca–Fe oxides in iron ore sintering machines

*K.MORIOKA et al.*

To decrease NOx emission from iron ore sintering machines inexpensively, a new process removing NOx within the sintering bed, named "In-bed-deNOx", was studied. This process utilizes the effect of Ca–Fe oxides, named CF, on NOx elimination reaction. This report describes the reaction behavior of NO on mainly the CF liquid surface and the application study of "In-bed-deNOx" to actual sintering process.

The effect of CF on the NO elimination reaction was investigated in the crucible experiments. Reaction gas containing about 400 ppm NO was blown onto the specimen in reaction tube. The NO concentration in outlet was measured in the range of 800°C to 1 400°C, and 0.2 to $10^{-17}$ mole fraction of oxygen. The CF, including ferrous oxide, shows the higher NOx elimination ratio. The NOx elimination ratio increases with increasing temperature and decreasing oxygen potential.

To verify the "In-bed-deNOx" process, some pot tests and experimental operations in the Kakogawa sintering plant were carried out. Firstly, the sintering pot tests were carried out by means of charging the CF pellets prepared in advance. NOx emission decreases with the increasing CF pellets addition. Secondly a sintering pot test was carried out by means of using limestone powder. NOx emission from the case of using limestone powder is as little as the case of charging CF pellets. An actual plant test was made by means of using fine limestone. Decreased NOx emission was achieved during the test period.

(cf. *ISIJ Int.*, **40** (2000), 280)

## Saving Energy

### Thermodynamic analysis of thermochemical recovery of high temperature wastes

*T.AKIYAMA et al.*

This paper describes a feasibility study of direct heat recovery system from high temperature wastes over 1 700 K by using objective chemical reaction, in which enthalpy-exergy diagram, so-called thermodynamic compass, is introduced for evaluating various systems. Blast furnace slag was taken as an example for the evaluation and familiar endothermic reactions in the cement production, the chemical industry, *etc.* were selected as a combination process for the heat recovery. Exergy analysis of cement and methanol plants was also carried out for further discussion.

The results showed that decomposition of limestone, reforming of methane and gasification of carbon are the most promising for heat recovery of the high temperature wastes; various slag and LD gas, from a viewpoint of effective use of exergy, not energy. This also appeals a possibility of next generation symbiotic steelworks with heat cascade utilization, rather than heat recovery.

(cf. *ISIJ Int.*, **40** (2000), 286)

### The use of LCA for the environmental evaluation of the recycling of galvanised steel

*C.V.-WHITE*

Life Cycle Assessment has been used to compare the environmental performance of landfilling of the zinc used for galvanising steel with recycling by a number processes. Hypothetical process routes were composed involving three different EAF dust treatment processes, Waelz kiln, DC-furnace, and EZINEX, as well as scrap dezincing. The study shows that recycling of zinc used for galvanising steel clearly has environmental benefits in that it saves zinc resources. However, zinc recovery does not necessarily decrease the potential impact on global warming and acidification. The magnitude of these two impact categories is tightly correlated with the amount and type of primary energy consumed in a process. Due to the high electricity consumption in the dezincing process, this route has the highest impact on Global Warming Potential as well as Acidification Potential. The major part of the energy requirement for the production of zinc from primary and secondary sources is consumed in the

reduction of ZnO to Zn. The consequence is that the theoretically possible saving in primary energy by recycling zinc-containing materials is relatively small. The impact categories land use and waste generation are not considered in this study, but most likely the evaluation of such impacts would further increase the potential environmental impact of the landfill alternative. The results also show that the location of an electricity-intensive process highly affects the potential environmental impact. Comparing process and material alternatives in LCA studies where branch average data is used is therefore considerably more complex than when LCA is used within a company.

(cf. *ISIJ Int.*, **40** (2000), 292)