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RECYCLING OF STEEL PLANT WASTE OXIDES — A REVIEW

C.J. ADAMS

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RECYCLING OF STEEL PLANT WASTE OXIDES - A REVIEW

by

C.J. Adams*

ABSTRACT

Iron and steel manufacturing produces large quantities of ferruginous waste that for economic and environmental reasons should be recycled. Such material consists of iron ore and coke fines, furnace dusts, water treatment plant filter cakes and sludges, and mill scale. These wastes amount to 8-12% of steel production from integrated plants and about 4% from non-integrated electric arc steelmaking plants. Most of it cannot be recycled directly to blast furnaces because it is either too fine or too wet, or is contaminated with zinc, lead and alkalis.

Processes for recycling wastes are based mainly either on direct-reduction kilns or rotary hearths. Electric smelting and cupola smelting of composite pellets of waste oxide and carbon have been developed to pilot-plant scale. Steelmaking dust, contaminated with zinc, can be pelletized or briquetted and treated effectively by several pyrometallurgical methods which volatilize the zinc during iron oxide reduction.

High capital and operating costs, and the need for large tonnages, favour regional recycling plants to serve several companies. However, a need exists for in-plant waste oxide recycling processes which are attractive economically on a small scale for electric furnace steel plants. Pelletizing systems are available commercially but options to recycle flue dusts which are contaminated with zinc and lead are severely limited. A process in which an induction furnace is used as a smelting-fuming-slagging unit is suggested.

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RECYCLAGE DES REBUTS D'OXYDES PROVENANT DE L'INDUSTRIE SIDERURGIQUE - COMPTE RENDU

par

C.J. Adams*

RESUME

L'industrie de la fonte et de l'acier engendre une grande quantité de rebuts ferrugineux qui par souci d'économie et de protection de l'environnement devraient être recyclés. Ces matériaux sont composés de minerai de fer et de fines de coke, des poussières de fours, des dépôts et des boues des filtres des usines d'épuration des eaux et des dépôts d'usine. Ces rebuts consistent de 8 à 12% de la production totale d'acier dans les aciéries intégrées et environ 4% de la production dans les aciéries non-intégrées à four électrique. La plupart de ces matériaux ne peuvent pas être recyclés directement aux hauts-fourneaux car ils sont soit trop fins ou trop humides ou sont contaminés avec du zinc, du plomb et des alcalins.

Les méthodes de recyclage des rebuts sont basées principalement sur les fours de grillage à réduction directe, ou les fours rotatifs.

La fusion électrique et la fusion dans le cubilot des boulettes composées de rebuts d'oxydes et de carbone ont été mises au point à l'échelle pilote. La poussière d'aciérie contaminée de zinc peut être transformée en boulettes ou en briquettes et traitée efficacement au moyen de plusieurs méthodes pyrométallurgiques qui volatilisent le zinc pendant la réduction de l'oxyde de fer. Comme les coûts de premier établissement et d'exploitation sont très élevés et que de très gros volumes d'approvisionnement sont nécessaires, il est préférable qu'une usine de recyclage régionale desserve plusieurs compagnies. Il existe tout de même un besoin pour des dispositifs de recyclage des rebuts d'oxydes à l'intérieur de l'usine qui, en petit, sont attrayants du point de vue économique pour les aciéries à four électrique. Des systèmes de pelletisation sont disponibles sur le marché mais ceux ayant l'option de recyclage des poudres de carneau contaminées de zinc et de plomb sont très restreints.

Dans ce rapport, on suggère une méthode selon laquelle un four à induction peut être employé comme dispositif de fusion-combustion-scorification.

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INTRODUCTION

Large quantities of ferruginous waste material are produced at steel plants as a byproduct of iron and steelmaking processes. Much of this material is recycled through sinter plants to blast furnaces but the rest is discarded on dumps or used as landfill. In recent years, however, the industry has become increasingly aware that it must respond to economic and environmental pressures and develop the necessary technology for efficient internal recycling of most waste material. Inquiries from industry and a suggestion from the Canadian Steel Industry Research Association (CSIRA) via its poll entitled "Technological Barriers to Progress" have prompted this study by CANMET under the Minerals Research Program. This review outlines the sources and types of waste material generated and documents processes that have been developed to recycle these wastes.

SOURCES OF WASTE

The sources of waste are many and varied. Preparing feed for blast furnaces produces coke, ore, pellet, sinter and limestone fines in volumes amounting to about 5% of the material processed. Blast furnace ironmaking produces dry coarse dust and wet sludge equal to about 4% of the iron produced. Basic oxygen steelmaking produces dry grit and wet sludge equal to about 1% of the steel produced. Electric arc steelmaking produces a dry fine dust equal to about 2% of steel production. A variety of scales and scarfings grouped under the heading of "mill scale" are formed at continuous casting units, soaking pits, reheating furnaces and rolling mills and are equal to about 4% of the steel processed. The quantities of waste oxides arising from iron and steel production vary from one plant to another, but for integrated plants it generally amounts to 8-12% of steel production. Waste produced by non-integrated electric-arc steelmaking plants would be about 4% of their steel production.

CHEMICAL ANALYSES OF WASTES

Wide variations in chemical analyses of the different types of waste may be expected, especially considering the variability in operating practices and feed materials. Approximate analyses of ferruginous wastes are listed in Table 1, mainly to indicate the per cent content of components which may be expected. The table shows that dust and sludge from blast furnaces contain considerable carbon. This is mostly coke fines formed by abrasion during movement of the burden down the shaft, but lately operators have been using oil injection through the tuyeres which may create considerable soot. Steelmaking dust may have a high zinc level when the steel scrap charged to the furnace contains galvanized steel or other zinc-containing material. This is especially true where the charge for electric-arc furnaces consists for instance 100% of shredded automobile scrap. In addition, steelmaking dusts usually contain some lead, amounting to about 10-20% of the zinc content.

RECYCLING STRATEGIES

Recycling of steel plant waste oxides has a long history and hence, for this study, it is considered best to cite major papers and reviews that can readily be obtained from the open literature. Cavaghan and Traice (1), Relf (2), and West (3) review recycling strategies of interest to the British Steel Corporation (BSC) and present data on chemical, mineralogical and size analyses of wastes arising within BSC. Proceedings of a McMaster University Symposium entitled "Waste oxide recycling in steel plants" document efforts of American and Canadian steel companies to solve their recycling problems (4). The Japanese seem to be more advanced because of their more stringent space limitations and pollution control regulations and have concentrated mainly on direct reduction in rotary kilns (5,6).

The fine waste material produced from feed preparation and furnace off-gas cleaning

Table 1 - Approximate chemical analyses of ferruginous wastes arising from iron and steel manufacture

	Per cent by weight, dry basis								
Waste material	Fe Total	Fe^{2+}	C	S	Zn	CaO	SiO_2	Al_2O_3	MgO
Blast furnace									
Dry dust	39	16	25	0.3	0.3	5	7	3	1
Sludge	42	10	20	0.3	0.3	5	7	3	1
Basic oxygen furnace dust and sludge	58	7	0.5	0.1	3	9	2	1	2
Electric-arc furnace dust	37	2	0.4	0.4	5-20	9	3	1	1
Mill scale	74	48	0.5	0.1	-	-	2	-	-

cannot be charged directly to the blast furnace because the dust would be blown back out of the furnace, and because fine material within the shaft creates erratic, uncontrollable operation due to loss of burden permeability. More important, there is ample evidence that tramp elements such as zinc, lead and alkali metals which become concentrated in the fine dust can seriously reduce blast furnace productivity (3,7,8).

Traditionally, integrated steel companies have recycled the fine material from coke, ore, pellet, sinter and limestone screenings through their sinter plants. However, problems arise in attempts to recycle blast furnace and steelmaking dusts and mill scale through a sinter strand. The very fine dusts are difficult to handle (9), sludge introduces considerable water, and mill scale is frequently contaminated with oil which, after being volatilized, causes pollution control problems (10,11,12). In addition, zinc, lead and alkalis from the contaminated dusts remain in the sinter and cause problems later in the blast furnace. Clearly, other means should be used to recycle contaminated waste oxides.

ZINC REMOVAL FROM WASTE OXIDES

During the 1960's, most integrated steel companies recognized their recycling problems and began to characterize their dusts and do bench-scale studies. Most of this early work is hidden in internal company reports and only comes to light during descriptive reports of pilot-plant trials. One notable exception is an excellent paper by Hogen in which open hearth, basic oxygen furnace and electric furnace dusts are characterized both physically and chemically (13).

It can be reasoned that recycling waste flue dust would be much simpler if the contaminants, particularly zinc, could be removed from the dust as a first step in a recycling strategy. Accordingly, the U.S. Bureau of Mines reported on a number of bench-scale investigations in which steelmaking dusts containing zinc were mixed with carbon and given a reduction roast to volatilize the zinc (14,15,16). Electric furnace flue dusts containing up to 25% zinc were mixed and pelletized with 10% coke breeze and roasted in the absence of air at 1050°C. After a two-hour roast the pellets were reduced completely to sponge iron, and more than 90% of the zinc had been removed. In addition, sodium and calcium chlorides added as catalysts were found to enhance the rate of zinc removal. Goksel studied the removal of zinc from basic oxygen furnace (BOF) flue dusts contaminated with 5% zinc by adding various amounts of coal fines and heating in a nitrogen atmosphere for different times and at different temperatures. He achieved complete zinc removal and iron metallization in pellets containing 11% carbon after 15 min at 1260°C (17).

A similar study was made at CANMET in which BOF dust containing 3% zinc was mixed with different carbon types, such as lignite char or coke fines, pelletized and heated to either 900 or 1100°C within an atmosphere of flowing nitrogen (18). As lignite char is a more reactive carbon source than coke fines, it greatly enhances iron oxide reduction and zinc removal. Pellets containing 20% char, reacted for one hour at 900°C attained greater than 90% iron oxide reduction and greater than 90% zinc removal, considerably more than when using coke fines. However, when pellets were reacted at 1100°C, zinc removal at 98% was similar for both types of carbon. The use of 7% $CaCl_2$ as a catalyst promoted zinc removal from pellets containing coke fines during treatment at 900°C. Coke fines plus $CaCl_2$ were found to be nearly equivalent to lignite char for zinc removal.

Hydrometallurgical methods to leach zinc from waste oxides have received some attention but are fraught with difficulties (13,16,19). Leaching operations are for the most part restricted to the recovery of zinc in the form of zinc oxide because zinc ferrite, silicate, aluminate and sulphide are not readily leachable from iron oxides. These four compounds, especially zinc ferrite, can account for up to half the total zinc content in steelmaking flue dusts. In addition, since dry BOF and electric furnace flue dusts are mostly less than 1 µm, there would be a significant loss of leachant due to physical absorption of the liquid and chemical dissolution of iron. Should the leachant be sulphuric acid, reaction with the lime in the flue dust creates a further contaminant - calcium sulphate. Residues from sulphuric acid leaching can contain up to 2% sulphur which probably precludes their recycling.

PILOT PLANT AND COMMERCIAL RECYCLING EFFORTS

Concurrent with concern for waste oxide recycling, developments were occurring in direct reduction. A process path in which iron ore pellets were prereduced to sponge iron and melted in an electric-arc furnace was seen to be a viable alternative to the blast furnace-BOF route to steel. It was reasoned that if waste oxides resulting from the more usual methods of producing iron and steel could be pelletized and reduced directly to iron, then disposal problems would be solved and additional iron units would be made available for steel production. Adequate zinc removal by volatilization during reduction of the iron oxides had already been demonstrated.

The treatment of waste oxides for zinc removal in kilns had its origin in Germany in the 1920's where the Waelz process evolved for treating low-grade zinc ores and was then adapted to treat zinc smelter fumes and dusts. Early pilot-plant trials designed specifically to treat steelmaking dusts in Canada and the U.S.A. are described by Thom and Schuldt (20) and by Holowaty (21). The Steel Company of Canada Ltd. (Stelco) at Hamilton, Ontario developed the SL/RN kiln process for direct reduction of iron ore pellets. Concurrently, the pilot-plant kiln was used for several years in the early 1960's to develop a process for recycing open hearth and BOF steelmaking dusts (22). In essence, the dusts were pelletized and fed to the kiln along with coke breeze or other suitable carbon source as reductant. The counter-current flow of gases and solids made it possible to obtain a high degree of zinc removal because the cleaner solids met cleaner gases. The upward flow of reducing gases generated by the reduction reactions within the pellet bed carried the zinc vapour from the pellets into the main gas stream where it was swept out of the kiln and captured as zinc oxide in a dust collection system.

Several processes are being operated commercially, all based on the rotary kiln concept. In Japan are the Kawasaki process (3,23), SL/RN at Nippon Kokan (NKK) (3,6) and the Sumitomo process (5). In West Germany, the Krupp-Codir process has been developed over the past decade (24,25,26) and a new process based on the original Waelz kiln process has been developed at the Berzelius zinc smelter in Duisberg (27,28). No plants have been built specifically in North America to treat zinc-contaminated steelmaking dusts.

Treatment of waste oxides in a rotary kiln has been successful and is the dominant method. However, other methods have been tried at pilot-plant scale and, although they have not become accepted commercially, most attained a measure of technical success. Holley and Weidner reported on the pelletizing of zinc-bearing dust and heating in a rotating hearth furnace to remove 95% of the zinc (29). The Surface Combustion Division of the Midland-Ross Corporation piloted its Heat Fast process in which waste oxide pellets containing ground coke or coal were fed into a rotary hearth metallizing furnace (30).

The Dominion Foundries and Steel Company (Dofasco) in Hamilton, Ontario developed an agglomeration and reduction process in which waste oxides, containing about 13% carbon from blast furnace dust and sludge, were extruded, dried and transferred into a rotary hearth furnace (31). The carbon in the extruded pellets reacted with the iron oxides and zinc compounds to form metallic iron, zinc vapour and carbon monoxide which was burned with secondary air above the bed. The zinc vapour oxidized within the off-gas and evolved as a white fume. The resultant metallic iron pellets were of sufficient strength and quality to be fed to blast furnaces, but their sulphur content (0.26%) and low metallization (80%) precluded their being recycled to steelmaking furnaces.

The McDowell-Wellman Engineering Company developed an electric ironmaking plant and process in which steelmaking dust, mill scale and carbonaceous blast furnace dust and sludge were blended, pelletized and fed to a Dwight-Lloyd travelling grate machine (32,33). The pellets were preheated and semi-metallized on the grate and then fed directly into a submerged-arc electric smelting furnace to produce molten high-carbon pig iron.

Recently, a process in which composite pellets of iron oxide and carbon are smelted in a cupola-type vessel was patented by Obenchain but results from pilot-plant trials remain unreported (34). The concept and design of such a process seem deceptively uncomplicated, but operating difficulties have apparently been experienced. Goksel speculated that during smelting, the pellets broke and pulverized into fine material which was blown from the cupola. He claimed that stronger pellets produced by a cold-bonding method known as the MTU process (described later) could be smelted successfully, but, as in his tests the pellets comprised only 5-10% of the iron charge to a cupola, perhaps his claim is overstated (35).

The most thorough investigation to date on cupola smelting of composite briquettes was performed by Gransden et al. at CANMET (36). It was undertaken primarily to find a suitable means to smelt a low-grade iron ore which could not be beneficiated satisfactorily into a concentrate suitable for blast furnaces. Iron ore, lime and lignite char were briquetted using an asphalt binder and charged with coke to a cupola. The carbon content of the briquettes was chosen to effect complete reduction of the iron minerals to iron during heating within the shaft. Molten iron and slag collected in the cupola well and were tapped separately. Heat for the process was supplied by the burning coke bed and not by the carbon contained in the briquettes which was only sufficient to satisfy the reduction reactions. A variation of this process has been proposed whereby composite briquettes of steel plant waste oxides and carbon are to be smelted in a cupola (37). It is understood that pilot-plant tests are proceeding, but no information has been released.

An extended-arc flash reactor has been developed at the University of Toronto but has not yet progressed to the pilot-plant stage (38, 39). In essence, blended waste oxides containing carbon are dropped through a column or flash reactor, then through a plasma zone, and finally collected as a molten bath in the hearth. The plasma is created by an extended arc between graphite electrodes. The arc is stabilized by introducing an appropriate gas, usually argon, through axial holes drilled through the electrodes.

THE CANADIAN SCENE

In some countries, especially Japan, waste oxide recycling is well advanced and is part of their overall industrial strategy. In Canada and the U.S.A. processes have been piloted successfully, but have not been built on a commercial scale for both physical and financial reasons. Most steel plants do not produce enough zinc-bearing wastes to warrant a separate recycling plant and, with the exception of a few areas in North America, these steel plants are usually separated by considerable distances and hence cannot form cooperative intercompany treatment facilities. The Hamilton area is probably the only location in Canada where there is sufficient concentration of steel production to make such an approach feasible. Financially, a very low rate of return on investment has discouraged even the most forward-thinking companies.

In Canada, three of the five integrated steel companies i.e., Sysco, Stelco and Algoma, recycle the bulk of their waste oxides through sinter plants. However, steelmaking flue dusts containing high percentages of zinc are not recycled. Dofasco has no sinter plant at present but intends to build one and so continues to stock-pile. Sidbec-Dosco feed directly-reduced sponge iron pellets, produced by the Midrex shaft reduction process, into electric-arc steelmaking furnaces. This type of direct-reduction unit offers no opportunity to recycle dusts or mill scale. There are a further 14 non-integrated steel producers in Canada who melt steel scrap in electric-arc furnaces and collect the ensuing flue dust in baghouses. These companies dump the dust and stock-pile a portion of their clean mill scale.

In discussion with several Canadian steel companies about waste oxide recycling problems, Viens and Banks concluded that for large integrated steel plants, technically feasible recycling processes have been developed, but much of this technology cannot be utilized by the smaller, non-integrated plants (40). They recommended a search for, or development of, recycling technology that is economically attractive on a small scale to benefit the smaller electric furnace steel plants.

The following sections deal with this objective. Agglomeration of dusts and mill scale by pelletizing or briquetting and methods of recycling or disposal are reviewed.

PELLETIZING AND BRIQUETTING

The control of fume and dust from electric-arc furnaces usually involves the entrapment of the fine particulate matter in fabric dust collectors, more commonly known as baghouses. The extremely fine dust, mostly of less than 1 µm is collected in hopper bins beneath the baghouse ready for disposal, presumably by being trucked to a dump. Transferring, trucking and dumping this dust can create further air pollution problems. Also, there is the possibility that rainwater may leach heavy metals from the dump and contaminate the local groundwater. Alternatives which are inexpensive and available without extensive development costs are not easily found. Moreover, the problem may not be viewed by operators as being particularly important because for every ton of dust some three tons of slag also needs to be dumped.

Agglomeration of flue dust and mill scale is probably the first step in any recycling scheme. Most of the agglomeration processes for recycling waste materials have been designed for the larger integrated steel plants, but some may be adapted to a smaller scale.

An agglomeration process utilizing a cold-bonding mechanism is desirable because it would avoid the costly step of high-temperature induration normally associated with conventional iron ore pelletizing. A Swedish process for pelletizing iron ore has been adapted for steel mill wastes in the U.S.A. called the IMS-Grangcold process (41). Waste material and about 10% portland cement are ground, blended and pelletized. The unhardened or green pellets are embedded in their own fine material feedstock to prevent distortion and sticking during the first stages of curing. After a few days the pellets are removed from the fines by screening and are stockpiled up to a month to cure depending on the type of cement used and the hardness required. However, it was found that zinc has an adverse effect on hardening time and prevents the cement bond from developing its full strength. This process is more likely to be used for recycling waste material to blast furnaces. Cement is costly and adds gangue material to the pellets; hence, this process is an unlikely candidate for smaller steel plants.

Two pelletizing processes have been developed which use hydrothermal reactions between lime and silica to form a calcium hydrosilicate bond. The COBO process (42,43), developed in Sweden, and the MTU process (44,45,46) developed in the U.S.A., mix finely ground lime and silica with materials to be pelletized. The pellets are hardened in high-pressure steam-heated autoclaves for about two hours at 2130 kPa (21 atm) pressure or for longer times at lower pressures. Costs for building a recycling plant based on this type of pellet bonding are considerable and hence would limit its application to a regional plant serving several steel companies.

A carbonate-bonding process has been developed in which hydrated lime and water are mixed with the iron-bearing material and then pelletized using conventional balling equipment (47). The wet pellets are partially dried in a rotary drier and then reacted with carbon dioxide in a rotary carbonator to chemically harden the pellets by converting the lime to calcium carbonate. This process was developed originally to provide iron ore pellets for blast furnace smelting, but it has not been accepted commercially for that purpose. However, for that purpose it merits a renewed evaluation for it could provide pelletized waste materials for recycling to other types of furnaces.

A novel idea has appeared recently which suggests that whey or lactose which are byproducts of cheese and butter processing, can be used as a binding agent for pelletizing waste iron oxides or for briquetting coal dust and sewage sludge into fuel briquettes (48). It is claimed that the use of whey is more efficient than other binding methods and that the iron ore pellets do not crumble at high temperatures.

Fine dusts wetted with the proper amount of water will ball or pelletize naturally when tumbled on a rotary disc or in a drum. Special binders may not be necessary if the pellets do not need to be exceptionally strong. Pelletizing steelmaking dusts without special binders or high-temperature induration has become known as "green balling" and several companies have been developing this recycling approach (49,50). Many companies are green balling for convenience of disposal (49), but Bethlehem recycles material to open hearth and basic oxygen furnaces with moderate success (50). Two U.S.A. engineering companies, Mars Mineral Corp. and Ferro-Tech Inc., have developed pelletizing systems which can be adapted to individual plant disposal or recycling needs (49).

Hot briquetting of waste oxides was pioneered by Dofasco in the early 1960's, but success at that time was frustrated by die wear problems (51,52). Since then, several commercial systems have been developed, all of which produce briquettes as feed material to blast furnaces (53,54,55). Dofasco also developed a process for recycling waste oxides by first forming extrusions and then reducing these agglomerates in a rotary hearth furnace (31). The complexity and cost of these systems severely limit their use on a small scale.

RECYCLING OPTIONS FOR SMALLER STEEL PLANTS

Of the options open to large integrated steel plants for recycling waste materials, recycling all but zinc-laden steelmaking flue dust and oily mill scale to a sinter plant is preferred. Steelmaking dusts are best treated by pelletizing and converting to sponge iron pellets using a rotary kiln; e.g., the SL/RN direct reduction process. Capital and operating costs would probably hinder an individual company from building such a system to treat only its own dusts, but a regional processing plant serving several companies may be a solution to the problem. Nevertheless, even if a regional plant were built, presumably at Hamilton, Ontario, the problem of transportation would still remain for the smaller steel plants located outside this major steel producing area.

Options for the smaller plants which melt steel scrap in electric-arc furnaces seem to be limited, especially when one considers that their flue dusts usually contain high levels of zinc and lead. Environmental considerations or regulations may well prohibit dumping in the future, hence solutions will have to be found even if the value of the recovered material is not enough to cover capital and operating costs.

The simplest route to follow would be to pelletize the dust and mill scale fines by green balling or, if stronger pellets are desired, by carbonate bonding and recycling the pellets directly to electric-arc furnaces. Possible adverse effects on the steelmaking operation have been noted or can be surmised (1,50). The pellets may break up and revert to dust when exposed to high temperatures and, hence, may increase the dust loading on the collection system. There would be an increase in the amount of slag and sulphur to the furnace, and an increase in electrical energy needed to melt the pellets. On the positive side, through recycling, the zinc content of the recirculated dust may be increased to a level, say 50% where it may have value as feed to a zinc refinery.

Many of the larger integrated steel companies have concluded that it is more logical to consider a separate processing unit to treat waste oxides instead of overloading their major steel refining furnaces. It was indicated previously that reduction of waste iron oxides to metal and dezincification of the pellets were enhanced considerably by adding carbon to the pellets. This can be achieved by blending into the mixture a proper proportion of carbonaceous blast furnace dust, coke breeze or char. A separate smelting unit such as a cupola-type shaft furnace has some attractive possibilities, especially where supplies of carbon and coke are available within the same plant. Non-integrated electric steelmaking plants, however, would need to purchase both, making cupola smelting considerably less attractive from their point of view. Development of a process for recycling in-plant flue dust and mill scale fines suitable for smaller electric steel plants has been neglected. In the absence of published articles on this aspect, the following process route is suggested as a topic for exploratory discussion.

An inexpensive carbon such as lignite char should be ground and blended into the waste material and the mixture pelletized in one of the small pelletizing systems offered commercially (49). These composite oxide-carbon pellets should be dried or, if necessary, hardened by carbonate-bonding (47). A line-frequency induction furnace of suitable size for the tonnage to be treated is chosen as the smelting, fuming and slagging unit. A bath of high-carbon iron is maintained in the furnace beneath several centimetres of slag, and pellets are fed continuously into the slag. When heated, the pellets become self-reducing and self-fluxing; iron oxides are reduced to iron; zinc and lead compounds are reduced; and these metals are volatilized. A fume extraction hood, perhaps water-cooled, should fit over the mouth of the furnace, but not too tightly as air should be drawn in to burn carbon monoxide, the off-gas formed by the reduction reactions. The air also should oxidize the zinc and lead vapours to form a whitish fume. A small separate baghouse should collect this fume which would have a very high zinc content, and hence may be a byproduct of considerable value. Iron may be tapped from the furnace periodically and cast into small ingots ready for recycling to the electric-arc steelmaking furnaces while the slag may be discarded.

A process route such as that described above would need to be assessed technically as well as economically before any company would consider it seriously. Development and capital costs are the usual reasons for delaying action on problems which are not immediately critical to production. A government-industry cooperative development program may be needed.

CONCLUSIONS

A review of literature published on waste oxide recycling in steel plants has shown that:

1. The larger integrated steel companies have well-developed processes for recycling most of their in-plant waste materials. The preferred method is to recycle these wastes through sinter plants to blast furnaces. Steelmaking dusts contaminated with zinc are the exception and are not recycled mainly because zinc has a deleterious effect on blast furnace operation.
2. Steelmaking dust contaminated with zinc can be treated separately by reduction processes such as the SL/RN rotary kiln process developed by Stelco or the extrusion-rotary hearth process developed by Dofasco. Pyrometallurgical conditions for dezincification of steelmaking dusts are well established. Bench-scale research projects should be considered only if the necessary information is unavailable.
3. Economic factors favour a regional processing plant serving the recycling needs of several steel companies. However, even if a regional recycling plant proved feasible, problems would remain for those steel plants located outside the region. As a result, a need exists for in-plant flue dust and mill scale recycling processes which are economically attractive on a small scale to benefit the smaller electric furnace steel plants. Pelletizing systems are available commercially, but options to recycle flue dusts which are contaminated with zinc and lead are severely limited. A process route in which an induction furnace is used as a smelting-fuming-slagging unit is suggested.

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