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Original Research

Selected Aspects of Metallurgical and Foundry Furnace Dust Utilization

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Abstract

One of the biggest problems in the metallurgical and foundry industries is the large quantity of dust generated during production processes. The most important is furnace dust created when the molten metal is prepared and subsequently sucked out by the dust removal system. At the Department of Foundry, experiments using the pneumatic injection method were carried out to utilize these kinds of materials and some results were successfully introduced into industrial applications. The results of dust injection into cupola and metallurgical EAFs (for slag foaming) were presented in this paper. The ideas behind the industrial set-ups, the process parameters, and the results obtained are described. The paper proves that pneumatic the injection technique could and should be continuously considered as an effective method for waste dust utilization.

Keywords: pneumatic powder injection, waste utilization, metallurgical furnace, furnace dust, powder injection lance

Introduction

Almost every metallurgical process generates a large quantity of various kinds of waste. Major pollution released into the atmosphere during the steel making process includes solid particles (dust), carbon (II) oxide, nitrogen oxides, and some volatile organic compounds. Due to its chemical and physical properties, the electric-arc furnace dust (EAFD) was strictly categorized as hazardous waste in most countries [1-4].

Many researchers claimed [1-5] the most harmful component of all the waste is furnace dust caught by dust removal systems of melting furnaces. EAFD contains a variety of hazardous elements such as Zn, Cd, Pb, and Cr (Table 1).

The seriousness of the electric-arc furnace dust disposal problem arises from the fact that the annual output created in the electric steel making process is constantly increasing. A total of 20 kg of dust per ton of steel is produced which, according to reports [1, 2, 6], results in millions of tons of dust created annually. A similar problem, although on a smaller scale, exists in foundry plants for casting alloy melting processes and, according to [7], one type of foundry (cast iron) is considered in reports to produce 750-800 tons/day of waste, where 30 tons from bulk mass are furnace dust.

Nowadays when environmental protection and cleaner production are one of the most important issues and when pollution limits for countries and companies are very tight [4, 6], the problem of metallurgical wastes becomes a strategic one. The metallurgical or foundry plants are obliged to utilize their own wastes or forward it to specialized plants for further processing when its potential impact on the environment is minimized and it could be transferred to another branch for utilization.

Being considered as potentially dangerous, wastes must be stored in specialized landfills. On the other hand, due to high content of several useful elements, i.e. zinc, they can be used as secondary raw material in the production of this

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Table 1. Typical example of EAFD chemical composition (%) [22].

Fe	42.00	Mg	1.61	Cr	1.05	Cu	0.24	Mo	0.07
Zn	13.30	Pb	1.34	K	0.97	Ni	0.19	Al	0.29
Ca	4.28	Si	1.29	Na	0.84	P	0.17	Co	0.05
Mn	1.90	C	1.10	S	0.32	Cd	0.11	-	-

metal or other products. These considerations have led to the special treatment of dusts and thus to reduction of their environmental impact. There are several possibilities to manage EAFD: hydrometallurgical and pyrometallurgical processes [8] or their inactivation, i.e. their stabilization prior to permanent disposal [4], the use of some fractions of dust in cement/concrete production [2, 9, 10], the utilization of dusts in the glass-ceramic industry [5, 10], and so on. One of the methods of EAFD and other furnace dust utilization is its pneumatic injection into various kinds of metallurgical/foundry furnaces [11-16] in-house, which is the method with still high potential to grow, resulting in new industrial set ups being applied.

To make the dust injection method possible and environmentally friendly, it is necessary to know first the exact nature of dust (grain size, chemical analysis, density, particle shape, etc.) and secondly to its proper preparation (by means of special chemical, heat, or other type treatment) before injection. That is why many authors have reported their research on furnace dust to describe its features and parameters and to suggest how to treat different kinds of such material [2, 11-19].

Since Poland has became a part of the EU, our metallurgy and foundry industries face problems that in "old" EU countries have been worked out with good results already. So the issue of waste management both in metallurgy and foundry is under consideration both in practice and experimental works. Our paper is the result of such an approach, giving the examples where cooperation between scientific and industrial partners gives new effective and economical results, making the furnace dust problem relatively easy to manage.

Experimental Procedures

One of the methods for utilization of furnace dust from any melting furnace is pneumatic powder injection directly into metal bath back into furnace. In the Department of Foundry, Silesian University of Technology, Poland, such experiments have being performed successfully for many years. Nowadays, Poland operates more than ten industrial set-ups for powdered carburizer injection, installation of furnace dust injection back to the melting furnace (both EAF and cupola furnaces), or pneumatic inoculation of cast iron [14, 20-22]. All of the industrial applications described below were previously thoroughly examined under laboratory and semi-industrial conditions. The Department of Foundry possesses quite a unique (among Polish research institutions) semi-industrial set up for powdered materials pneumatic conveying tests as well as research stands for physical modeling of the powder injection into liquid process. The obtained results could be easily transferred into real installations and conditions with high accuracy.

Dust Injection into Cupola

According to literature data and the authors' own experiences the cupola melting process creates between 4 kg/t and 15 kg/t of molten cast iron, depending on the charging materials, furnace type and quantity of coke used (or not for cokeless cupolas). In Germany alone, cupolas generate more than 30,000 t of dust per year [21]. The dust being sucked out includes many valuable elements that are additionally very harmful (mainly Zn, Pb, Cd). The Fe content is generally higher than 10%, so the dust itself is a valuable charging material. When the dust contains >15% C it can be an extra source of heat as a real fuel. Since nowadays a bigger and bigger part of the charge materials for cupolas (sometimes up to 40%) comprises automotive scrap, mainly zinc-coated sheets, the high Zn content in cupola dust appears to be a serious problem. The zinc content in the dust may increase up to 20% which means it can be used as a charge material for the metallurgical process in zinc metallurgical plants. Moreover, repeated recirculation of dust into the cupola causes an increase in the economical factors of this approach.

Results and Discussion

At the Department of Foundry the experiments of re-injection of cupola dust together with the finest fractions of ferrosilicon and anthracite (considered as wastes) were carried out and resulted in several installations. The examples of two Czech foundries based on cupola melting were described in the paper. The first problem to solve was the conveying parameters adjustment to make possible pneumatic dust transportation. After dust parameters analysis and provisional experiments it was observed that it is necessary to prepare a mixture of dust with other materials to make it pneumatically transportable. The result was mixture compositions as shown in Table 2.

The experiments were carried out using an experimental stand built in the Department of Foundry and one of the most important results was a industrial stand implemented in cast iron foundry (Fig. 1). On the basis of the experiment's results, the industrial stand was designed and produced by Cooperation POLKO Mikolow, which is the company the department has been cooperating with for many years.

Table 2. Properties of materials injected into cupola.

Material	Bulk density (kg/m^3)	Grain size (mm)	Humidity (%)	Mix. 1	Mix. 2
Cupola dust	630	<0.5	<3.5	-	50%
FeSi	1860	0-3	<1.3	50%	50%
Anthracite	880	0-2	<2.8	50%	-

The powder pneumatic feeder was prepared with electronic control and precise dosing systems (inside the required flow range 2-5 kg/min.). The continuous recording of the feeder's mass changes with accuracy ±0.1 kg makes possible real-time estimation of powdered material outflow and in the same way the final efficiency of the injection process. The specific requirements of melting require that dosage time (with good flow stability) should be about 2 hours. During the industrial experiments the powdered material was conveyed through a flexible pipeline of L=25 m length and inside diameter d_w=0.025 m from pneumatic feeder to the end of installation (injection lance introduced into furnace). Moreover, the design changes of the mixing chamber (the area on the feeder's bottom where the powder mixes with carrier gas flow) have been made. There was a porous liner below that allows fluidization powdered material into the container. The research assumptions include a strictly given range of the powdered material mass flow equal to m_c=0.033-0.083 kg/s (2-5 kg/min), but the most important parameter is the conveying stability inside the entire working cycle.

The values of mass flow rate of powder during experiments were in the range m_c=0.0332-0.1075 kg/s (2-6.5 kg/min) and were precisely inside requirements. The preliminary research carried out were the basis for selection of constructional parameters of the real injection system (the supplying nozzle diameter d_3=5mm) and pressure of the carrier gas (p_3=0.3-0.4 MPa), which guarantee the stability of the diphase stream flow.

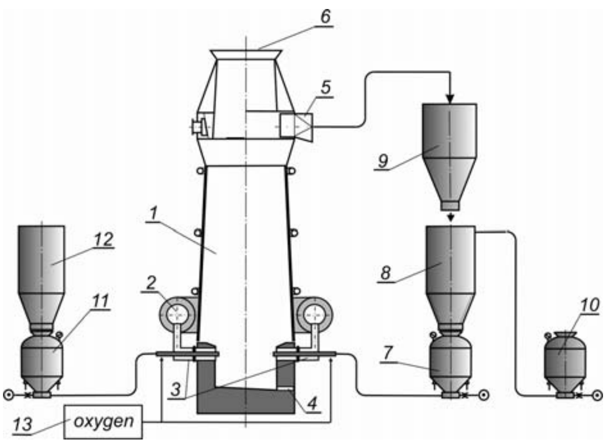

Fig. 1. Industrial cupola dust injection set up; 1 – cupola, 2 – wind box, 3 – cupola nozzles, 4 – tapping hole, 5 – dust removal system, 6 – charging door, 7 – dust-coal mixture pneumatic feeder, 8 – dust-coal mixture container, 9 – dust storage container, 10 – coal pneumatic feeder, 11 – ferroalloys pneumatic feeder, 12 – ferroalloys storage container, 13 – oxygen blow.

The presented cupola modification except of obvious environmental advantages, provided the following technological and economical results:

- considerable reduction of production costs,
- increase of cupola effectiveness up to 50% if compared to normal melting process,
- coke consumption decrease up to 10%.

EAF Dust Injection for Slag Foaming

One of the disadvantages of the electric arc furnace melting process is the bad effect of arc itself on the furnace lining by means of heat damage [11, 15]. Moreover, heat loss for the process without slag foaming is twice or even four times greater than when the foaming is present [11, 15, 22, 23]. Therefore, several techniques have been developed to cope with this problem and the most effective is slag foaming with use of pneumatic powder injection system [15]. Slag foaming is based on the process of CO bubble formation when powdered carbon (or other material with high enough carbon content) is introduced together with oxygen into liquid metal bath just under its surface. As an effect, the slag increases its volume and covers the arc, making the process more controllable and enhancing the furnace lining life. Special pneumatic devices with blowing lances are necessary to inject the foam-creating materials exactly in the reaction zone. Looking for the best and most cost-effective materials for that process as well as for possible EAF waste utilization methods, the EAFD had been considered as reagent for slag foaming chemical reactions. The experiments in that field were carried out in the Department of Foundry for the EAFD taken from one of the Polish steel plants with the dust chemical composition as shown in Table 3.

Table 3. Chemical composition of EAF dust.

Material	Content, %	Material	Content, %
$Fe_{(total)}$	20.61	FeO	2.53
SiO_2	3.12	Al_2O_3	0.61
CaO	3.19	MgO	2.20
Mn	3.19	Zn	30.63
Pb	5.80	K_2O	2.04
Na_2O	2.42	P	0.15
S	0.67	C	0.92
F	0.20	-	-

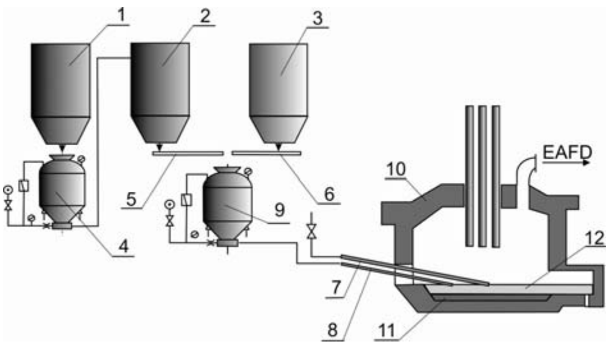

Fig. 2. The industrial set-up for EAFD-coal mixture pneumatic injection into 65 tons EAF: 1 – furnace dust container, 2 – intermediate dust container, 3 – dust pneumatic feeder, 4 – powdered coal container, 5 – dust feeding screw, 6 – coal feeding screw, 7 – oxygen lance, 8 – mixture injection lance, 9 – mixture pneumatic feeder. 10 – EAF, 11 – liquid metal, 12 – slag.

After the laboratory experiments, the pneumatic devices and process parameters were proposed and adjusted and industrial set-ups were prepared for EAFD-powdered coal mixture pneumatic injection into 65 tons electric arc furnace (Fig. 2). The mixture preparation in proportion 3:1 (3 parts dust to 1 part powdered coal) was necessary to make conveying the fine dust pneumatic easier and controllable and to ensure a proper carbon amount to start foaming reactions. Without that the dust had a hanging-up inside feeder tendency or the transportation was not uniform (called often pulsatory or portion).

The research made both in laboratory and in industrial conditions proved the effectiveness of the slag foaming process with use of the mixture proposed and pneumatic injection equipment accuracy. During the industrial experiments a total of 278 controlled heats were performed with various material compositions as follows:

- 42 heats with coal injection only for slag foaming (for comparison),
- 69 heats with EAFD-coal mixture injection (25% coal and 75% dust),
- 167 heats with EAFD-coal mixture injection (90% dust and 10% coal).

The prototype of the slag foaming installation for 65 tons EAF is characterized by the following parameters:

- furnace dust grain size: 0.005-0.5 mm,
- bulk density of dust: 489 kg/m^3,
- powdered coal grain size: 0-3 mm,
- bulk density of coal: 667 kg/m^3,
- maximum amount of the mixture injected during one melt: 1,330 kg,
- mass composition of the mixture: 75% dust + 25% coal,
- injection time: 10-15 min,
- system capacity: 0.5-2.2 kg/s,
- unitary oxygen consumption: 2-4 m^3/Mg,
- unitary dust consumption: 5-11 kg/Mg,
- unitary coal consumption: 1-3 kg/Mg.

The results of the industrial stage of research were exactly as predicted after laboratory work and seem promising. The average EAFD amount possible to introduce is 10.58 kg/ton of steel (average total amount for one heat is 903.6 kg/ton). With such a factor the final dust production is 51% lower than previously in the steel plant being analyzed. After several blowing-in processes, the final dust was enriched to above 30% zinc and about 5% lead content, making it rich enough to be a secondary raw material in the production of these metals. Additionally, the slag foaming by means of EAFD-coal mixture results in coal consumption 0.3 kg/ton of steel less and oxygen 1.56 Nm^3/ton of steel less than when only coal-based slag foaming was performed.

Conclusions

We have presented the use of the pneumatic powder injection for furnace dust utilization. The experiments with cupola and EAF dusts were performed at the Department of Foundry, Silesian University of Technology over the last few years. The examples show how the pneumatic injection technique could be used to utilize furnace dust, giving both good economical and environmental results. A similar process can be used for utilization of other powder/dust wastes created in steel plants/foundries, such as crushed electrodes or fine ferroalloys or carburizers fractions (considered often as waste). The experiments with powdered waste plastics pneumatically introduced into cupola furnaces (problem not described in the paper) were conducted by some authors as well with promising results, but it is still under consideration and needs further experiments and development. Laboratory experiments as well as industrial applications of such processes were carried out by authors, too. The ecological and economical indexes of industrial applications are good and the interest of the industry continuously increases.

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