

# INFLUENCE OF ADDING IRON-STEEL WASTE MATERIALS ON HOT METAL QUALITY <sup>1</sup>

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## Abstract

Hazardous waste materials, notably industrial ones, are of particular concern, inasmuch as if they are not dealt with adequately, they may pose a serious threat to the environment. In this connection, those industries which develop reuse and/or recycling policies for their wastes in their own manufacturing processes, next to addressing the environmental issue, will, to some degree, be replacing their waste generation by co-products. Further, the gain will be even more substantial if reuse is followed by a lower energy and/or feedstock consumption. This paper looks into the behavior of some waste materials from the iron-steel industry, such as BOF fine sludge, rolling scale and iron oxide stemming from the Acid Regeneration Plant (ARP), aimed at their recycling as treatment agents to pre-refine hot metal. Lab tests suggested that such waste materials from the iron-steel industry may be used as ancillary agents to pre-refine hot metal. However, since lab test results are not absolute, industrial trials are being conducted and the preliminary results are quite promising.

**Key words:** Wastes from the iron-steel industry; Desulfurization; Dephosphorization.

## INFLUÊNCIA DA ADIÇÃO DE RESÍDUOS SIDERÚRGICOS NA QUALIDADE DO GUSA <sup>(</sup>

### Resumo

Os resíduos perigosos, produzidos, sobretudo pela indústria, são particularmente preocupantes, pois quando incorretamente gerenciados, tornam-se uma grave ameaça ao meio ambiente. Nesse sentido, as indústrias que desenvolverem políticas de reaproveitamento e/ou reciclagem dos seus resíduos no próprio processo produtivo, além de solucionar uma questão ambiental, estarão, de certa forma, substituindo a geração de resíduos por co-produtos, e o ganho será ainda maior se o seu reaproveitamento resultar em redução do consumo de energia e/ou matéria prima. Esse trabalho avalia o comportamento de alguns resíduos siderúrgicos, tais como, lama fina de aciaria, carepa de laminação e óxido de ferro da Unidade de Regeneração de Ácido (URA) visando a sua reciclagem como agentes de tratamentos de pré-refino do gusa. Os ensaios laboratoriais demonstraram que estes resíduos siderúrgicos podem ser empregados como agentes auxiliares no pré-refino do gusa. Todavia, considerando que os resultados dos ensaios laboratoriais não são absolutos, estão sendo realizados os testes industriais, sendo que os resultados preliminares foram promissores.

**Palavras-chave:** Resíduo siderúrgicos; Dessulfuração; Desfosforação; Dessiliciação.

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## 12 PREAMBLE

The manufacturing of steel products did develop substantially after the Second World War. Production costs saw a significant reduction, for example, through an optimized use of energy and input materials resources. Conversely, sourcing low impurity content raw materials has become a daunting challenge as they get increasingly scarce and more costly.

Furthermore, the ever-increasing requirements for steel cleanliness, ranging from extra-deep drawing to weldable structural steels, makes it necessary to produce steel grades with a rather low impurity content, based upon the sum total (sulfur + phosphorous + nitrogen + oxygen + hydrogen) of less than 100 ppm and, in particular, sulfur content less than 0.001%.<sup>[1]</sup>

In this connection, steelmakers in Brazil continuously strive to come up with alternatives to cut back on impurity levels without substantially impacting product's end cost. A potential opportunity appearing on the horizon is the use of waste materials coming from the iron-steel making process itself as ancillary agents in the refining process, or to even reuse them.

Being produced at all stages of mankind's activities, wastes, both in terms of content and volume, vary according to consumption practices and production methods. Issues of major concern include the extent to which they may impact human health and environment (soil, water, air and landscape). Hazardous waste materials, notably industrial ones, are of particular concern, inasmuch as if they are not dealt with adequately, they may pose a serious threat to the environment.

The 70s were the water age, the 80s were the air age and the 90s the solid waste age, according to Cavalcanti (1998). And these trends were not observed in Brazil only. In the United States, the solid waste approach also started in the early 80s, when the Superfund-specific legislation, whose main purpose was to recover the large solid waste landfills scattered across the country was created. And this approach resulted in the creation, by the Environmental Protection Agency (EPA), of a solid waste law under title No. 40 in the Federal Register.

According to Leripio (2004), we are the waste society, and we are surrounded by it, but only recently did we wake up to this sad aspect of our reality. He goes on to say that, over the last couple of decades, the world population has grown less than the waste volume produced by it. While between 1970 and 1990 the planet's population experienced an 18% growth, the amount of waste on the Earth experienced a 25% increase.

In Europe, the waste issue is marked by a strong concern about its recovery and energetic reuse. Because of the scarce resources available, Europe faces energy generation issues. This scenario is compounded by high energy consumption, which makes it wiser to recycle materials and make the most of their thermal potential.

On May 31, 2004, the Brazilian Association of Technical Standards (Associação Brasileira de Normas Técnicas – ABNT), issued the latest version of its NBR 10.004 on Solid Waste, which sorts waste as per their potential hazards to environment and public health, so that they can be managed adequately.

When it comes to waste management, the NBR 10.004 is a valuable tool, and is used by both institutions and overseeing bodies. From the classification set forth in the Standard, the waste producer may easily identify the potential risk involved and come up with the best alternatives for final disposal and/or recycling. This new

version sorts waste into three different classes: Class I (hazardous), Class II (non-inert) and Class III (inert).

To handle the industrial waste issue, Brazil has specific laws and standards. Among them is Article 225 of the Brazilian Constitution, which provides about environmental protection; Law 6.938/81, which establishes the National Policy on Environment; Law 6.803/80, which provides basic guidelines for industrial zoning in pollution-critical areas; resolutions 257/263 and 258 of the National Council for the Environment (CONAMA, Conselho Nacional do Meio Ambiente) which provide about batteries and pneumatics respectively. In addition to that, the issue is broadly tackled in Chapters 19, 20 and 21 of Agenda 21 (Rio-92).

In short, the Federal Government, by means of the Ministry of Environment – MMA and of the Brazilian Institute of Environment and Renewable Natural Resources – IBAMA, is developing a project to identify industrial waste through a domestic survey so that it may draft and develop an action policy aimed at reducing production and improper disposal of hazardous waste.

The approval, in the beginning of 1998, of the Law of Environmental Crimes, which determines heavy sanctions for those who dispose of waste unduly, led to an increase in the activities of waste management companies, and some of them experienced a 20% increase in the demand for services shortly after the law was enacted. However, there was a slight drop in demand after a Provisional Measure extending the deadline for companies to adjust to the new legislation was issued.

Comparing French and Brazilian legislations, Groszek (1998) states that they do not differ significantly from each other. Both Brazilian and European legislations share responsibility principles to be borne by the waste producer. In France, so too in Brazil, producers' responsibilities include, for instance, electing treatment sites which are both appropriate and environmentally correct. Also, they must pick haulers who are duly certified.

The operator, in turn, must observe overall legal obligations as well as those resulting from the specific operator's license.

The companies which have invested in industrial waste disposal and treatment technologies and facilities are relying upon ISO 14000, because companies adhering to the standard will have to adequately manage their waste, as well as on improved inspection by environmental control agencies.

When one looks at the National Solid Waste Policy (PNRS), currently under discussion in Congress, the insertion of the so-called "co-products" in the chapter on industrial and mining wastes, quote - *"shall not fall into waste category those by-products and co-products to which there is proven evidence of economic alternatives and environmental recyclability, within the industrial process itself, or reuse as either input materials or energy in other industrial processes or economic activities"*, one might say that this is a step in the right direction, as these materials are to be distinguished from those solid wastes which cannot in any form be used with the current technology.

In this connection, those industries which develop reuse and/or recycling policies for their wastes in their own manufacturing processes, next to addressing the environmental issue, will, to some degree, be replacing their waste generation by co-products. Further, the gain will be even more substantial if reuse is followed by a lower energy and/or feedstock consumption.

This paper looks into the behavior of some waste materials from the iron-steel industry, such as BOF fine sludge, rolling scale and synthetic iron oxide, aimed at their recycling as hot metal pre-refining treatment agents.

## 2 IRON-STEEL WASTE MATERIALS

### 2.1 Iron Oxide Coming from the Acid Regeneration Plant (ARP)

After hot rolling, a fine iron oxide layer (scale) is left on the steel strip surface. This layer cannot be removed by water spray, because it is quite thin and has a very strong mechanical anchorage. So, to clean the strip an aqueous HCl etching solution, known as pickling, is used. From this etching, the whole scale on the surface is removed and the strip subsequently either tin- or zinc-coated. Over time, iron ion concentration in the acid solution builds up, thereby curtailing pickling capability. Whenever a certain iron ion concentration is reached, it is necessary to either replace or regenerate the acid solution. In order to reclaim the acid solution from pickling process, CSN has an Acid Regeneration Plant (ARP).

At this plant, from the  $\text{FeCl}_2$  concentrated solution HCl (chloritic acid) solution is recovered and a solid compound consisting mostly of  $\text{Fe}_2\text{O}_3$  is formed. This synthetic iron oxide will henceforth be referred to as  $\text{Fe}_2\text{O}_3$  ura. At the ARP the solution coming from the pickling process is pumped into a separation vessel, where separation through concentration of ferrous chloride solution takes place. The solution with the greatest concentration is routed to the reactor, inside which burners provide energy enough to turn ferrous chloride ( $\text{FeCl}_2$ ) into  $\text{Fe}_2\text{O}_{3(\text{solid})}$  and  $\text{HCl}_{(\text{gaseous})}$ .

The gaseous fraction goes first through a cyclone for fines particulate removal - iron oxide - and afterward through an absorber for gas condensation. The particulate material is stored in bins, and later on transported by means of rail cars to the raw material yard to be used in the sintering plants. Part of this material is also sold as abrasive agent to shot blast metal parts prior to painting.

### 2.2 Rolling Scale

Before achieving its final shape and properties, steel goes through a number of processes from iron ore smelting reduction to coating, during which waste is generated. This waste may be put back into the iron- and steelmaking process, or alternatively transformed into co-products.

At CSN the final product is steel coil. CSN steel is, for the most part, used in the packaging and automotive industries. To meet such applications, steel requires a number of special properties, which are imparted as it passes through the different transformation processes: primary refining, secondary refining, continuous casting, hot rolling, pickling, cold rolling and coating.

After continuous casting, the slabs are fed into a Reheating Furnace till rolling temperature is reached, around  $1.200^\circ\text{C}$ . Because of air oxygen contact at this temperature, an oxide layer is formed on slab surface. This oxide layer is called "rolling scale".

Prior to being hot rolled, slabs are sprayed with water at a  $210 \text{ kg/cm}^2$  pressure to remove this oxide layer. The removed material - rolling scale - along with water, is routed to a pit, where separation through settling takes place. The scale is stored and periodically removed by means of a clamshell and then kept in rail cars.

Currently, some 9 thousand tons of scale are generated monthly, and fully recycled at the sintering plants.

## 2.3 Bof Fine Sludge

During steel primary refining in the LD Converters, under oxygen blow at a temperature of roughly 1.700°C, the off-gases produced in the process, bearing suspending solids, pass through a dedusting and cleaning system, resulting in oxygen gas and sludge. BOF sludge has two fractions (coarse and fine). Prior to being sent to thickeners, the coarse fraction is separated by a gravimetric system, and then directed toward storage tanks.

The remaining sludge is transported to thickeners which condense the sludge into a highly viscous slurry called “BOF fine sludge”. This BOF fine sludge, along with other waste materials generated in the different production steps and rich in iron and carbon, have been used to produce pellets, which are added to the Torpedo Cars.

## 3 MATERIALS AND METHODS

### 3.1 Design and Assembly of Dosing Device

A lab dosing device for pre-refining agents made from stainless steel was developed specifically for this study, using N<sub>2</sub> as carrier gas. Figure 1 shows a schematic drawing of this dosing system.

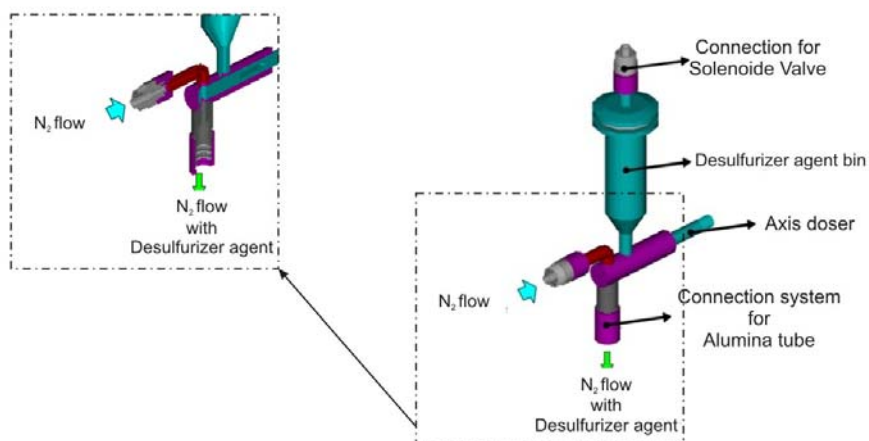


Figure 1: Schematic drawing of dosing system made to conduct tests.

### 3.2 Lab Tests

Waste materials: Rolling Scale (CL), Iron Oxide from Acid Regeneration Plant (OF URA) and BOF Fine Sludge (LFA) were collected straight at the source where they are generated, dried at 110°C and, later on, except for LFA, comminuted in a ring mill for 2 minutes. The wastes were characterized by chemical analysis (Inductive Couple Plasma-ICP), phase analysis (DRX) and morphological analysis (Scanning Electron Microscopy - SEM). The pig iron and slag used for lab testing were collected from the # 1 Iron Runner of CSN Blast Furnace # 2 .

The lab tests were performed in a Tammann Oven, Figure 2, located at CSN Research & Development Center. Also, a graphite cylindrical crucible was laid inside the oven chamber, which was filled with hot metal and slag in a 1:1 ratio. The tests were carried out at 1550°C, under N<sub>2</sub> atmosphere. As mentioned earlier, pre-refining

agents were injected into the bath and N<sub>2</sub> used as carrier gas. Hot metal was tested for silicon, sulfur and phosphorous content prior to and after each dosage.

In order to prevent dosing system from becoming blocked, waste fluidity was adjusted by adding granulated alumina from spray dryer and sintered at 1000°C in a 4:1 ratio. The increased viscosity and reduced slag activity, coupled with the alumina added, was circumvented by adopting a 1:1 hot metal/slag ratio. This procedure differs quite significantly from that industrially used in torpedo cars, in which slag is barely a thin layer upon hot metal bath.

Moreover, using alumina as inert material boosted operational safety, both in terms of preventing the dosing system from getting clogged and curtailing the amount of pre-refining agents added to bath at each dosage. As a result, less gas was produced from the reactions during testing.

## 4 RESULTS AND DISCUSSION

### 4.1 Physical-Chemical Characterization of Waste

#### 4.1.1 Iron oxide from acid regeneration plant

By using Helium Picnometry analysis, the actual average specific mass of iron oxide coming from the Acid Regeneration Plant - equal to 5.20 g.cm<sup>-3</sup> - was determined.

The chemical analysis, Table I, shows that the iron oxide stemming from the Acid Regeneration Plant consists mostly of Fe<sub>2</sub>O<sub>3</sub> (95%), and to a lesser extent, FeO (2.41%) and Fe<sup>o</sup> (0.55%). One can also notice that alkali content is quite low, less than 0.2%.

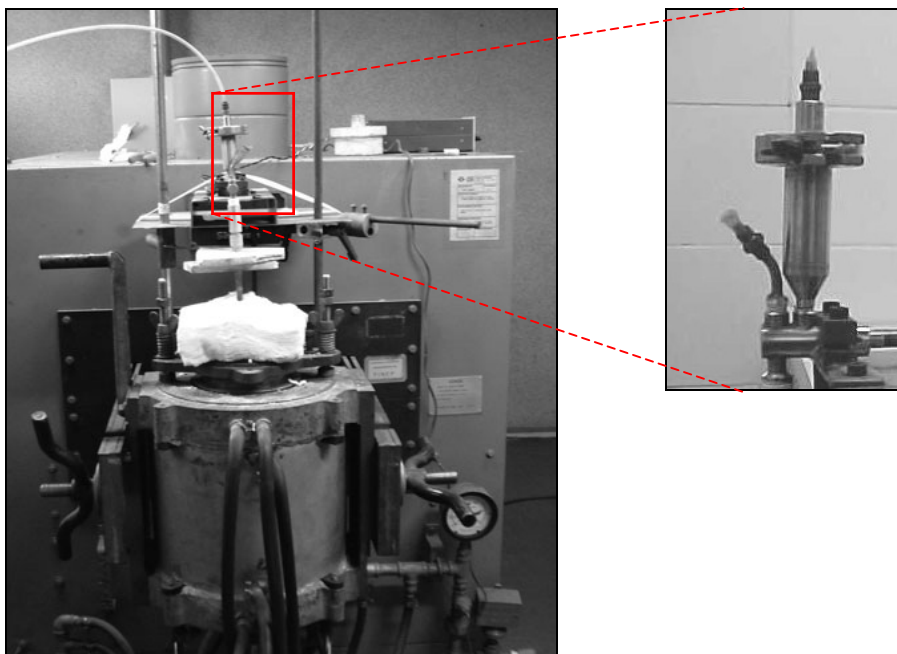


Figure 2 - Dosing system coupled to Tammann Oven.

Table 1. Chemical analysis of iron oxide from the Acid Regeneration Plant.

Compound	CaO	MgO	Al <sub>2</sub> O <sub>3</sub>	SiO <sub>2</sub>	FeO	Fe <sub>2</sub> O <sub>3</sub>	Fe <sup>o</sup>	Na <sub>2</sub> O	K <sub>2</sub> O	ZnO
[%]	0,16	0,02	0,21	0,55	2,41	95,91	0,55	0,17	0,01	0,03

In the phase analysis conducted by X-ray diffractometry, the hematite phase was the most prevailing one, Figure 3. Diffraction spectrum did not show the other phases, which may likely be ascribed to the rather low concentration of the other phases making up the material.

From SEM images, Figure 4, one can notice that the iron oxide stemming from the Acid Regeneration Plant has a spheroidal morphology, with diameters ranging from 0.5 to 2 mm, and uneven surface with low porosity.

#### 4.1.2 Rolling scale

By using Helium Picnometry, the actual average specific mass of rolling scale -  $4.32 \text{ g/cm}^3$  - was determined. From X-ray Diffractometry, one can notice that the rolling scale consists of two Fe-O system phases: FeO (wustite) and Fe<sub>2</sub>O<sub>3</sub> (hematite), Figure 5.

Quantitative chemical analysis showed that the wustite and hematite phases correspond, in terms of weight, to 51.81% and 20.47%, respectively, Table 2. Rolling scale has a rather low alkali and silica content.

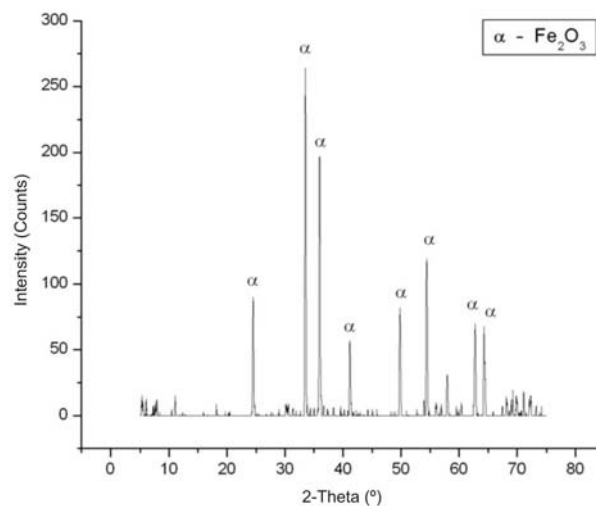


Figure 3 – Phase analysis spectrum produced from X-ray Diffractometry

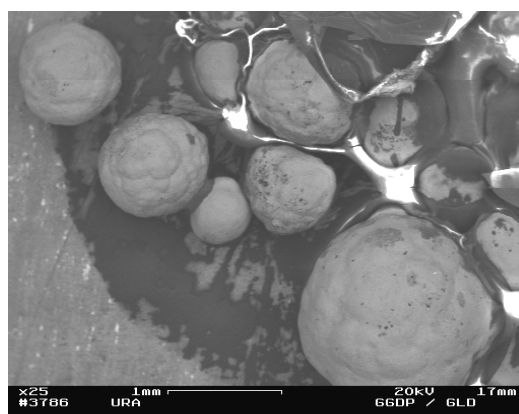
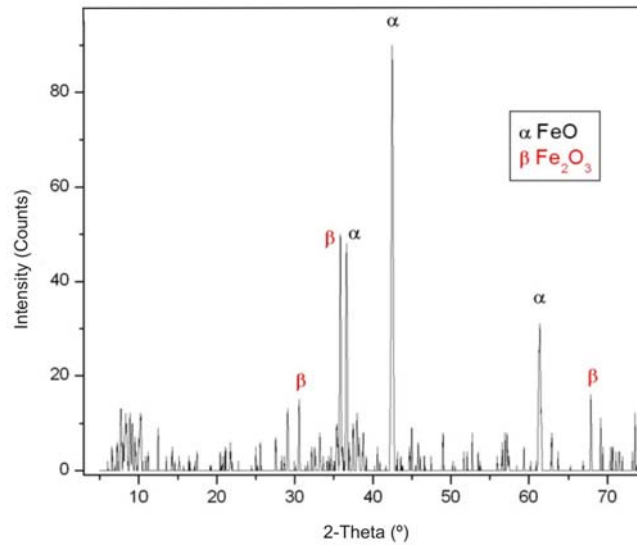


Figure 4 – Morphological SEM image of iron oxide from ARP.

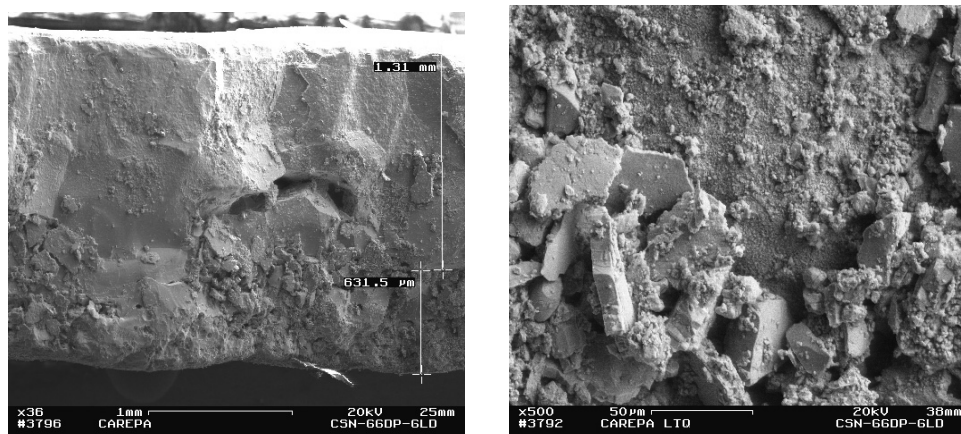


**Figure 5** – X-ray Diffractometry spectrum of rolling scale

**Table 2** – Chemical analysis of rolling scale.

Compound	CaO	MgO	Al <sub>2</sub> O <sub>3</sub>	SiO <sub>2</sub>	FeO	Fe <sub>2</sub> O <sub>3</sub>	Fe <sup>0</sup>	Na <sub>2</sub> O	K <sub>2</sub> O	ZnO
Contents [%]	0,16	0,02	0,19	0,55	70,22	27,74	0,89	0,18	0,01	0,03

Rolling scale has a lamellar morphology resulting from its formation process, Figure 6. In Figure 6a one can see that the scale has multiple layers formed during slab oxidation. Such layers depict iron oxidation states. In Figure 6b one can notice that the material also shows small fragments, which have the same morphology as that of the material, but in greater volumes.



**Figure 6** - Morphological SEM image of rolling scale.

#### 4.1.3 Bof fine sludge

Table III shows the chemical analysis of BOF fine sludge. One can notice that the main compounds are CaO, ZnO, MgO and iron compounds (FeO, Fe<sub>2</sub>O<sub>3</sub> and Fe<sup>0</sup>). Figure 7 presents the X-ray diffractogram of BOF fine sludge, consisting mostly of metal iron, iron oxides – wustite and magnetite, and calcium oxide.

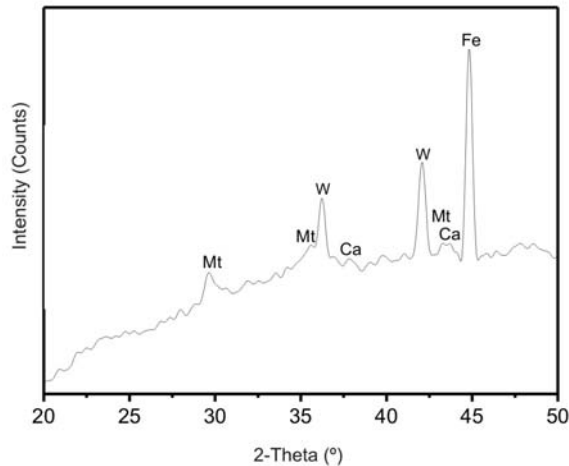
Correlating Table 3 with Figure 7, one can infer that BOF fine sludge consists mostly of iron oxides, 76.74%. Of this percentage, 57.23% are iron oxides in phases with crystalline structures of wustite and magnetite. The remaining portion is metal



iron related. As indicated earlier, the CaO found in the waste comes from lime added to the steel refining process in the LD Converters.

**Table 3**– Chemical analysis of BOF fine sludge.

Compounds	CaO	MgO	Al <sub>2</sub> O <sub>3</sub>	SiO <sub>2</sub>	Fe <sub>oxides</sub>	Fe°	Na <sub>2</sub> O	K <sub>2</sub> O	ZnO
Contents [%]	11,91	3,01	0,18	1,28	57,23	19,51	1,23	0,07	5,59



Ca = Calcium oxide; Fe = iron; Mt = magnetite; W = wustite.

**Figure 7** - X-ray diffractogram of BOF fine sludge

The low MgO content is owing to dolomitic lime being used to protect LD Converters refractory lining during refining process, which has also, to some extent, added to CaO content. The SiO<sub>2</sub> content comes from silicon oxidation found in hot metal and, also, from the slag process, consisting basically of calcium silicates. As to ZnO, its origin is associated with galvanized scrap recycling in the metallic charge of LD Converters. Aluminum oxide stems from aluminum oxidation used as deoxidizer in the molten steel.

The chart in Figure 8 shows the granulometric distribution of BOF fine sludge. The waste shows a particle size distribution ranging from 1 µm to 840 µm. One can notice that the sludge has an extremely fine granulometry, and 80% of the particles are smaller than 74 µm (200 mesh). The average particle size is 35.6 µm. The actual grain density, as found by helium pycnometry, is 4.29 cm<sup>-3</sup>.

In order to investigate the particle morphology of this waste, SEM analyses were conducted as shown in Figure 9. BOF fine sludge has a microstructure with particle sizes which are fairly variable. The larger particles are porous, consisting of iron oxides bound to the oxides of other elements. The smaller particles consist mostly of metal iron.

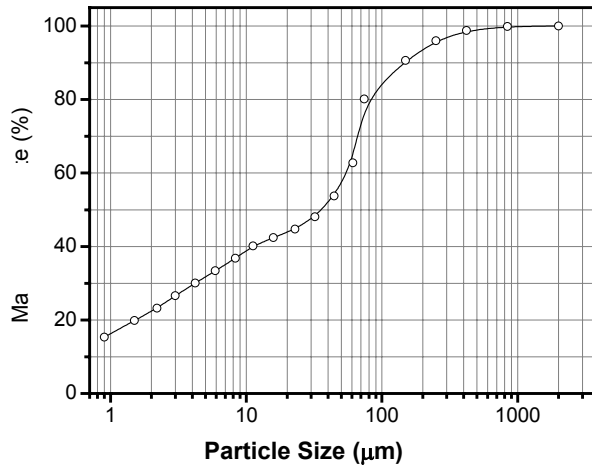


Figure 8 – Chart of BOF fine sludge particle size distribution.

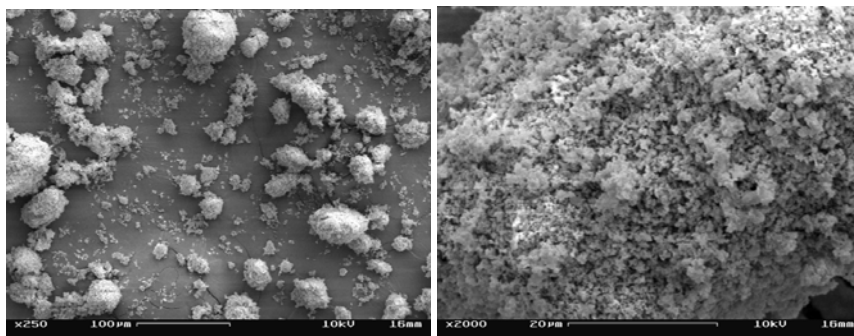


Figure 9 – Micrograph of BOF fine sludge particles.

#### 4.2 Grinding Granulated Waste (Iron Oxide from Arp and Rolling Scale)

Upon grinding in a disk mill, iron oxide and rolling scale share similar granulometric distribution, Figure 10, presenting average particle size of around 40 μm. When compared with BOF fine sludge particle size distribution, Figure 8, one can notice that BOF sludge has a greater fraction of particles below 10 μm. As to the iron oxide stemming from ARP and rolling scale, the fraction below 10 μm corresponds approximately to 20 and 40%, respectively.

As both materials, iron oxide from ARP and rolling scale, share similar particle size distribution, this fact may be ascribed to ring mill efficiency rather than materials' friability.

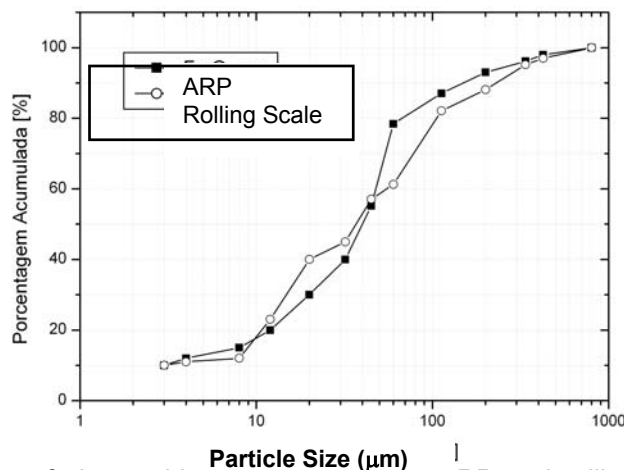
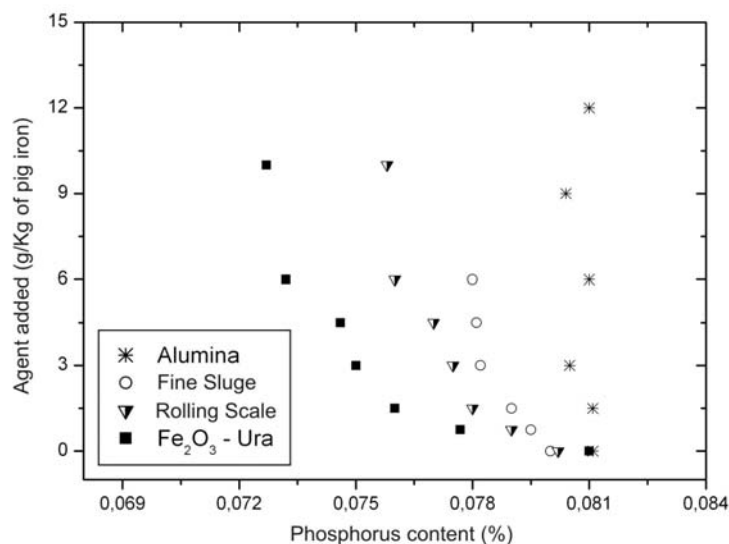


Figure 10 – Distribution of iron oxide particle size from ARP and rolling scale upon undergoing grinding in a ring mill.

## 4.3 Pre-Refining Lab Tests

### 4.3.1 Phosphorous

Figure 11 shows phosphorous content fluctuation in the process simulations of hot metal refining by adding different iron-steel waste materials. A particular simulation was run just adding alumina powder to hot metal. Phosphorous content remained virtually unchanged across the whole spectrum investigated, signaling alumina inert effect in hot metal refining process. When alumina was, however, mixed with iron-steel waste, the behavior was quite different. Adding alumina to rolling scale and BOF fine sludge did not bring about any significant changes, and both materials, following additions between 6 and 12 g/kg of hot metal, showed a trend to reduce phosphorous content in hot metal (dephosphorization). Adding iron oxide from ARP to hot metal meant an increased efficiency regarding dephosphorization, i.e., adding roughly 10 g/kg of hot metal resulted in a phosphorous content reduction in hot metal of the order of 7.69%. Considering that parameters such as temperature, reaction time, N<sub>2</sub> flow, etc., were the same (standardized) for all lab simulations, the best performance of the iron oxide stemming from ARP in connection with hot metal dephosphorization may be associated with the greater oxygen potential generated in the molten metal bath during Fe<sub>2</sub>O<sub>3</sub> decomposition process.



**Figure 11** – Fluctuation of phosphorous content in hot metal as a result of adding iron-steel waste

The technical literature says that the speed of a chemical reaction is proportional to the total concentration of material that may react (LEVENSPIEL, AVERY). Experimental data of deleterious elements reactions with iron-steel wastes corroborated this trend. Considering that  $E=E(t)$  is the amount present of a certain material at instant  $t$ , then one can say that the fluctuation rate  $E(t)$  regarding time  $t$ ,  $dE/dt$ , is represented by the Equation 1.

$$\frac{dE}{dt} = k \cdot E_{(t)} \quad (1)$$

where  $k$  is a negative constant, which is well defined from a physical perspective. Usually one considers  $E(0)=E_i$ , i.e., the initial amount of the material considered. Graphically speaking, the curve shows a negative exponential form, in line with Equation 2, as indicated in Figure 11.

$$E_{(A)} = E_0 \cdot e^{-kA} \quad (2)$$

Where:

- E**= Concentration of deleterious element upon adding waste;
- E<sub>0</sub>**= Initial concentration of deleterious element;
- A**= Added waste mass; and
- K** = Constant of reaction speed.

A way to confirm the exponential behavior of reaction drop between deleterious elements and iron-steel waste is by plotting Fig. 11 chart in semi-log scale, Fig. 12. By using the slope formula - interceptor, which may be applied to any linear relationship, Equation 3, one can determine the angular coefficient, k. This coefficient, or k factor, is the constant of reaction speed. As for phosphorous, the k values were as follows: -221,72 for iron oxide from ARP, -331,33 for rolling scale and -547,32 for BOF fine sludge, which shows that, of all wastes investigated, the iron oxide from ARP outperforms the other ones when it comes to removing phosphorous from hot metal. The most significant result of the study was to find that the iron-steel wastes which were investigated may be added to hot metal without substantially impacting metal's chemical analysis. Therefore, they ought not to be referred to as "waste" rather as "co-product".

$$y = mx + b \quad (3)$$

Where:

- y** = ln A;
- m** = slope = k;
- x** = E; and
- b** = linear coefficient (y axis interception).

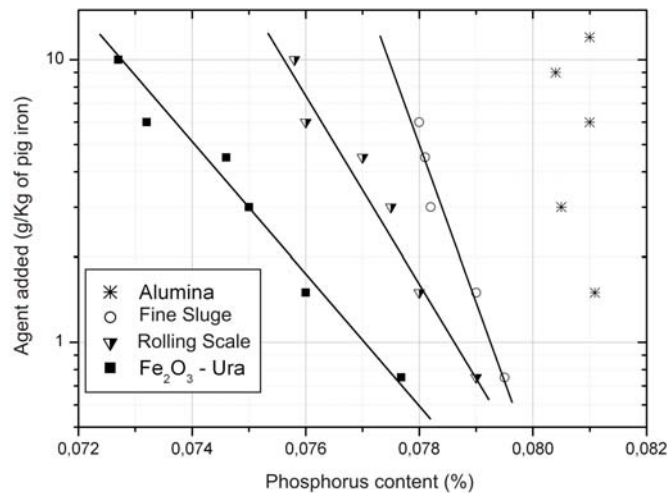
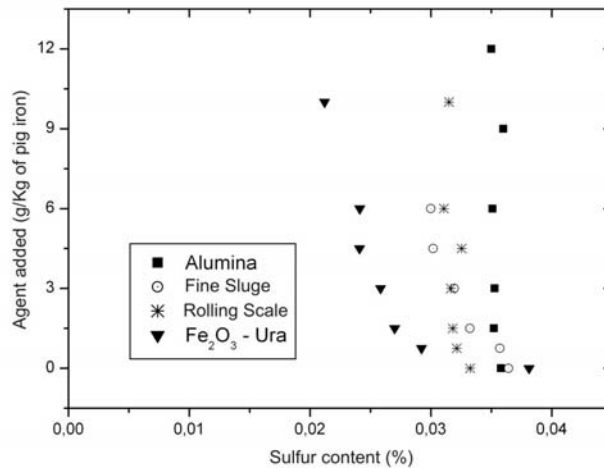


Figure 12 – Influence of adding iron-steel waste on hot metal phosphorous content.

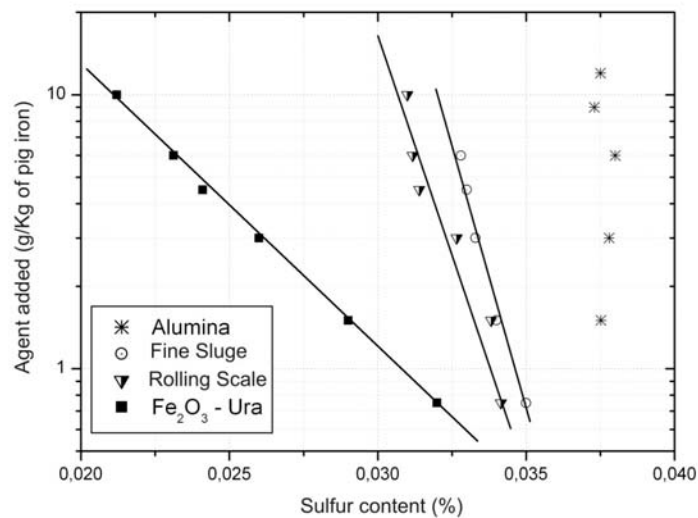
#### 4.3.2 Sulfur

Figure 13 shows sulfur content fluctuation as a result of adding iron-steel waste. Just as with phosphorous, Figure 11, upon adding alumina to the molten metal bath, sulfur content remained constant across the whole range. Adding rolling scale and BOF fine sludge did not bring about any significant changes, just a downward trend for sulfur content in hot metal. Yet, the iron oxide from ARP yielded the highest efficiency in terms of removing hot metal sulfur (desulfurization). Adding

roughly 9 g/kg of hot metal caused a decrease in hot metal sulfur content of approximately 34.21 %. As all parameters, such as temperature, reaction time, N<sub>2</sub> flow, etc., were kept constant (standardized) for all lab simulations involving hot metal pre-treatment, the greatest efficiency produced by the iron oxide coming from ARP in connection with hot metal desulfurization may likely be ascribed to the greater oxygen potential generated in the molten metal bath during Fe<sub>2</sub>O<sub>3</sub> decomposition process. The angular coefficients - k factors - arising out of Fig.14 chart were as follows: -102,92 for iron oxide coming from ARP, -287,14 for rolling scale and -405,29 for BOF fine sludge, corroborating the same “efficiency ranking” as that for phosphorous.



**Figure 13** – Fluctuation of hot metal sulfur content resulting from adding iron-steel waste.



**Figure 14** – Influence of adding iron-steel waste on hot metal sulfur content.

### 4.3.3 Silicon

Figure 15 shows the fluctuation of hot metal silicon content as a result of adding iron-steel waste. When pure alumina and a mixture of alumina with BOF fine sludge and rolling scale were added, there was an upward trend for silicon content in metal, most likely due to molten metal bath being stirred by N<sub>2</sub> flow, which raised bath-slag interaction rich in SiO<sub>2</sub>. Adding, however, iron oxide from ARP caused hot metal silicon content to drop (desiliconization), chiefly due to the greater role played by Fe<sub>2</sub>O<sub>3</sub> when compared with SiO<sub>2</sub>, leading to concurrent reduction reactions. With Fe<sub>2</sub>O<sub>3</sub> reduction in Fe<sup>0</sup>, there is an increase in oxygen potential in the molten metal

bath, which makes it somewhat difficult for SiO<sub>2</sub> to be reduced. Moreover, this is a rather unusual behavior, as by plotting the semi-log chart, Figure 16, one can notice that, on adding iron oxide from ARP, the ensuing behavior is non-linear, that is, k factor cannot be accurately determined. For the other two kinds of waste, rolling scale and BOF fine sludge, there was an inversion in the slope curve, owing to the increased Si dissolved in the molten metal bath as a result of it being stirred while waste was added.

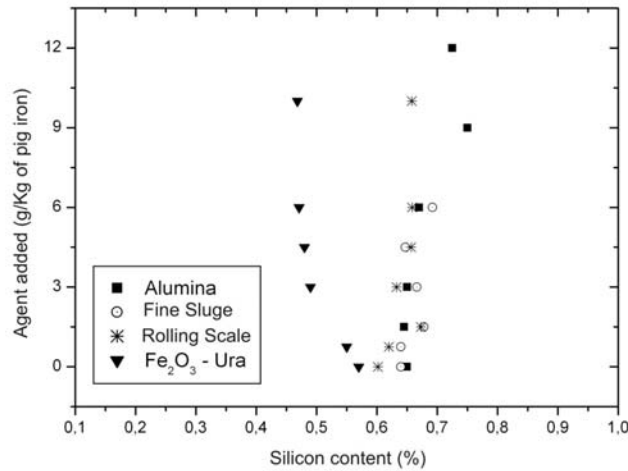


Figure 15 – Fluctuation of hot metal silicon content as a result of adding iron-steel waste.

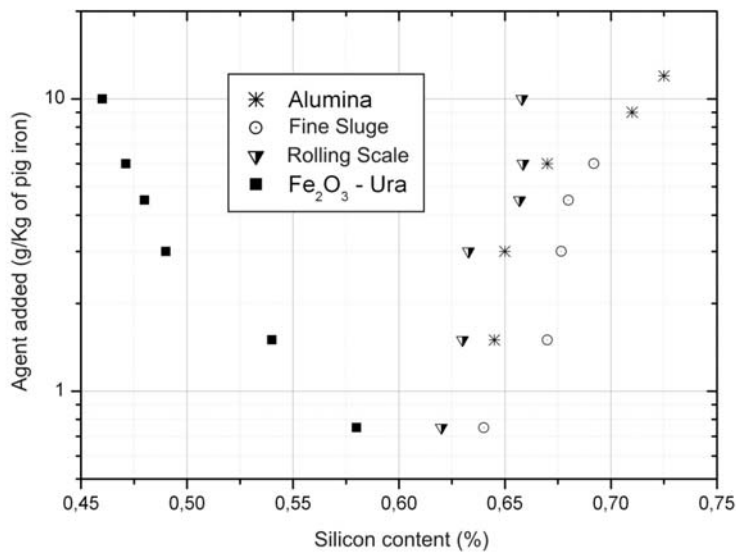


Figure 16 – Influence of adding iron-steel waste on hot metal silicon content.

## 5 CONCLUSIONS

The lab apparatus which was developed may be used for simulations involving different kinds of iron-steel waste or refining agents only adjusting powder fluidity by adding alumina powder.

The lab simulations conducted showed that the iron-steel wastes which were investigated, iron oxide from the Acid Regeneration Plant - ARP, rolling scale and BOF fine sludge, may be used as hot metal pre-treatment agents. The “efficiency ranking”, from the most to the least effective, was the same for the different deleterious elements making up steel quality (phosphorous, sulfur and silicon); No.1 iron oxide from the Acid Regeneration Plant; No.2 rolling scale; No.3 BOF fine

sludge. However, as lab testing results are not absolute, it is necessary to run pilot and industrial trials prior to industrial implementation.

This project will, in-a-not-too-distant future, make it possible for industrial waste to be recycled in the iron-steel making process itself. In addition to lessening the environmental impact caused by dumping these waste materials in landfills, they will henceforth be referred to as “co-products”, rather than “waste”.

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