УДК 621.745

A NEW METHOD OF RECYCLING OF PARTICULATE IRON-CONTAINING WASTES - THE WAY TO CREATION OF NON-WASTE PROCESSING AND UTILIZATION OF METALS IN INDUSTRY

S.L. Rovin, Ph.D., A.S. Kalinichenko, Dr.Sc., Belarusian National Technical University, Minsk, Belarus

The article presents an alternative method for recycling ferrous waste, based on a continuous solid-liquid phase reduction of iron oxides in rotary tilting furnaces (RTF). The new method allows the processing of waste from virtually any composition and state from metal to oxide and multicomponent (shavings, scales, sludges, etc.) contaminated with moisture, oils, organic impurities, without their preliminary preparation (purification, homogenization, pelletization, etc) to produce a cast iron or steel ingot or casting alloys.

Keywords: *recycling, reduction, disperse iron-bearing wastes, rotary tilting furnaces*

Introduction

Efficient use of recourses, including wastes utilization and recycling, is a matter of universal significance. In response to the burden mounting deficit and appreciation, recycling of disperse iron-bearing wastes, such as facing, scale, aspiration fines and grit (aspiration dust), which accumulation in dumps today commensurate with ore output, is of key significance.

Recently, in Metallurgy along with a traditional blast-furnace practice of iron production methods of direct ore oxide reduction, which seem may be also used for processing of industrial metal wastes, are rapidly on the rise. But at the formal resemblance of the processes it is practically impossible to use the engineering solutions existing in Metallurgy.

All the methods of iron direct reduction, as well as blast-furnace practice, maintain the differential process characteristic – burden must be in the form of lumps (pellets, agglomerates, briquettes). Lower size limit is 10 - 15 mm, while the upper one may be a sequence higher though it doesn't have heavy restrictions. The lower limit is conditioned by a layer mode and the size of the furnaces in use. Herewith not only size limitations, but also strict requirements to the burden density and resistance are attributed to operational and engineering characteristics [1].

At the same time it is understood that heat transfer and all the heterogeneous processes at the gas–solid interface, including solid-state reduction, involve maximum developed reagent specific surface area. Reduction (oxidation) rate is a direct function of material dispersion and porosity, first of all, of the apparent porosity [1, 2].

Such process conflict in Metallurgy is solved by increasing the furnace size both in two-stage and one-stage technique of iron production. Profitability of metallurgical facilities may be reached only by production ramp-up to about a million ton per year or even to higher values. Herewith, requirements to stability and uniformity of the charge stock, its composition, size, mechanical qualities etc., become prevalent ones.

However, dispersion and porosity of the original burden substance are considered to be negative characteristics. The above characteristics are aimed to be lowered by various approaches – the staff is pelletized, which highly increase the expenditures and the cost of the final product.

Recycling of the industrial metal wastes must be organized on a brand different basis. Consolidated metal wastes acquisition and processing inevitably results in uncontrolled mixing of dissimilar materials, which results in worsening their quality as iron source, needs comprehensive material handling and logistic systems, sophisticated equipment for treatment and preparation, melting, control and realization of the product, which makes the above product uncompetitive in comparison with traditional burden materials.

Small-tonnage recycling on a national scale does not signify low-powered, this means decentralized flexible production, organized directly at the enterprises-sources of waste generation.

Contents

Developed small-tonnage recycling is based on closed ecological system of metal recovery. Herewith material porosity and dispersion are positive characteristics, since processing is carried out in principally new facilities – rotary tilting furnaces (RTF).

Alternatively to traditional facilities working with fixed bed of lump materials, disperse materials in RTF are within a dynamic continually stirred layer being influenced by high-speed high-temperature loop-like gas flow with 25-35 m/sec circulation speed. Constant renewal (mixing) of the layer and its intensive blow increase manifold the processes of mass and heat transfer: in RTF volumetric heat transfer coefficient (α_v) reaches 2000-3000 W/m^3, while in a fixed bed of the material it is at the level of (3-4) W/m^3 [2].

In order to implement high-temperature and high-speed processes of heating, recovery and melting of disperse materials it was necessary to study gas and disperse materials flow patterns in RTF and to develop the above processes management practices.

For the research, a specially developed technique for simulation modeling and computer modeling using high-level programs were used.

Facilities modeling was carried out for furnaces of different types: for traditional short drum-type furnaces with rectilinear translation of the gas flow and for rotational tilting furnaces with loop rotational motion of gas (Fig.1.).

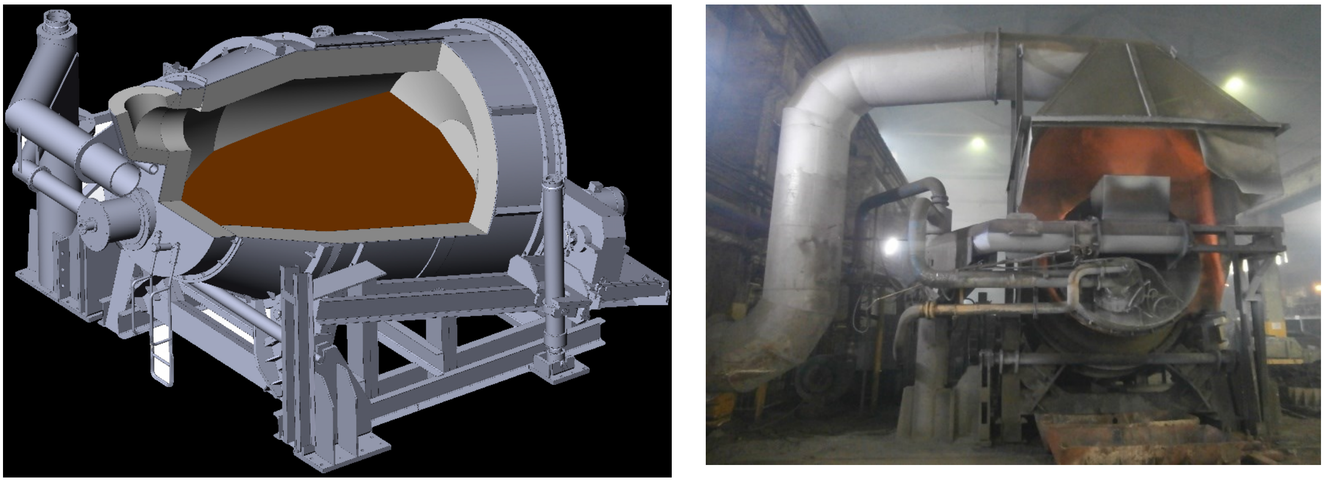


Fig. 1. – RTF General Drawing

The results of numerical simulation are the fields of temperatures, velocities and trajectory of the gas flow, an example of the solution is shown in Fig. 2.

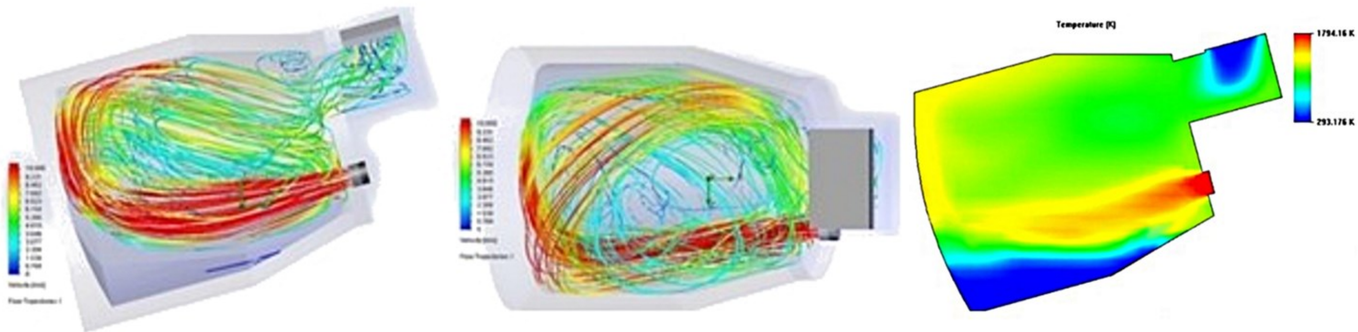


Fig. 2. – Trajectories and velocities of gas motion and temperatures in RTF.

Aerodynamics of the flow and its interaction with material depend on the burners disposition, their number and incidence angle, layer configuration, spinning speed, spinning axis tilting angle, etc., which makes such furnace the facility with controlled vector of heat carrier flow.

High speed gradient in the layer section and the pulse nature of the material motion in RTF provide high intensity of mixing and, as a consequence, that of heat exchange in the layer. According to the results of simulation and computerized modeling, equalizing of the composition and thus the temperature in the material layer in RTF goes on within 5-10 turnovers of the furnace body.

The results of simulation and computerized modeling made the basis for development of engineering solutions which have been successfully realized in practice.

Time of dense agglomerates reduction process, including pellets and agglomerates, amounting to 20 hours and more in the processes of direct nonblast-furnace iron-making is conditioned, first of all, by inside diffusion, and is proportional to the size of the reduced material.

As a basic model, accepted in iron and steel industry, describing the mechanism of agglomerates reduction process, the model with "unconverted core" [3, 5] is used. In compliance to the above model reactions of the reduction from highest oxide to metal (Fe_2O_3-Fe_3O_4-FeO-Fe) go at the reaction zone surface; reduced lower oxides (or metal) develop a particular barrier-shell round the unconverted core.

As the reaction zone moves deep into agglomerate the reduction speed decreases rapidly: first of all, the route of the reducing gas molecules, diffusing through the layer (shell) of the reduced material, and that of the reaction products re-diffusion grows, and secondly, reaction surface area decreases proportionally to a squared radius of the unconverted core.

When describing the reduction processes of porous disperse materials, such as scale, aspiration dust and metallurgical sludge, etc., use of the model with "unconverted core" does not reflect the actual conditions and is unacceptable.

Oxide particles have the sizes tens and hundreds times smaller than pellets, much less briquettes. Porosity of scale, aspiration dust and sludge, as a rule, is apparent, and is by two or three orders of magnitude greater than the agglomerate porosity, which during the process of reduction provides similar conditions of the exchange practically throughout the whole depth of the reduced particle. Studies have found that during the process of scale reduction in a dynamic layer at the temperature of 1100-1200ºC the degree of metallization reaches 75-80 per cent yet in 30 minutes.

In such conditions "quasi-homogeneous" model of the reduction process, based on the fact that reducing agent gets inside and simultaneously interacts with oxides throughout the whole mass, operating speed is equal and metallization goes on throughout the whole volume of the particle (layer element) simultaneously [2].

Adequacy of the "quasi-homogeneous" model use for description of the processes of solid-phase reduction (SPhR) of disperse materials in a dynamic blown through layer as well as high operational speeds have been supported also during reduction smelting of rolling scale in RTF pilot furnace at Bellorussian Metallurgical Plant, where SPhR-process did not exceed 2,0 – 2,5 hours [2].

Interaction nature of iron oxides with gas reducing agents and carbon is adsorptive-catalytic, which is promoted by fast-renewing surface: in RTF the material is in continuous spiral reciprocating motion actively being mixed, both in the section perpendicular to the rotation axis and longitudinally.

Fixed contact of dynamic layer with high-speed turbulent gas flow with CO/CO_2 ratio not less than 2/1, being in looping motion in furnace operating space, also facilitates mass-exchanging processes.

There has been growing the role of direct reduction at the expense of solid Carbon (C), that is present within the material layer both in the form of carbon soot and disperse and ultra-disperse particles: specific developed surface of reagents up to 1,5-2,5 m^2/g

contributes to the direct carbon interaction with iron oxides. Appearance of the excess CO amount over the material layer and also heavy frothing of slugs at the transition into the stage of liquid-phase reduction that finalizes the process of oxides recycling in RTF.

Hydrogen also plays an active role in reduction of porous (microporous) material. Hydrogen, originating due to H_2O conversion from the products of natural gas combustion, easily penetrates into micropores, which size is commensurate with molecule free path of ~ 0,5-0,7μ. Pores <1 μm make up 30-50% of the total surface of slag plates and sponge iron obtained. The presence of hydrogen accelerates the recovery process by 10-20%.

All the known methods of nonblast-furnace ironmaking from ore and industrial iron-bearing wastes may be divided into two groups, differing from each other by the method of oxides and final product reduction: methods of solid-phase reduction (SPhR), which final product is sponge iron, and liquid-phase reduction (LPhR), the final product of which is liquid iron [3,4].

Solid-phase oxides reduction and sponge iron production being the most developed and efficient processes, though rather time-consuming, do not solve the problem of complete replacement of the primary burden materials in full. Producing of high-quality dense materials, pig and casting alloys, is possible only by the method of their further re-melting in furnaces of different type, mainly in electric arc or induction ones, or in cupola installations.

High-speed LPhR-processes are rather energy-intensive, thus using such methods for reduction, starting from original composition, without first solid-phase reduction of oxides results in cost increase of the final product – cast iron and steel [4].

It seems that the most rational is the process of continuous two-stage reduction in one facility without overloading and transient heat loss. Herewith, heating, drying, oil burning-out and first materials reduction are carried out in solid state, and then after the optimal metallization level (70-80 %) has been reached and solid-phase reduction has been slowed down, the above process transits into high-temperature mode of liquid phase reduction to produce liquid iron and steel. Exactly such two-stage process was realized on the basis of the designed technology with use of RTF.

One of the main factors, hindering continuous two-stage process with transition from SPhR to LPhR, is bloom processing (agglomeration of reduced iron with slag and under-reduced material). Lumps (blooms) formation terminates the reduction process, hinders material smelting and liquid-phase reduction.

Thanks to high technological mobility RTF render it possible to overcome the above difficulty. The main part herewith is the rate of material heating during the transition period from 1100-1200ºC, temperature of SPhR conduct up to 1700-1800 ºC, temperature of LPhR realization. During experimental melting 5-6 minutes transition was a success while the heating rate was 2-3 K/sec.

Characteristics of the developed method of recycling in RTF, based on continuous solid- and liquid-phase reduction process that differ from the known technologies of direct iron production may be presented in Fe-C diagram (Fig. 3).

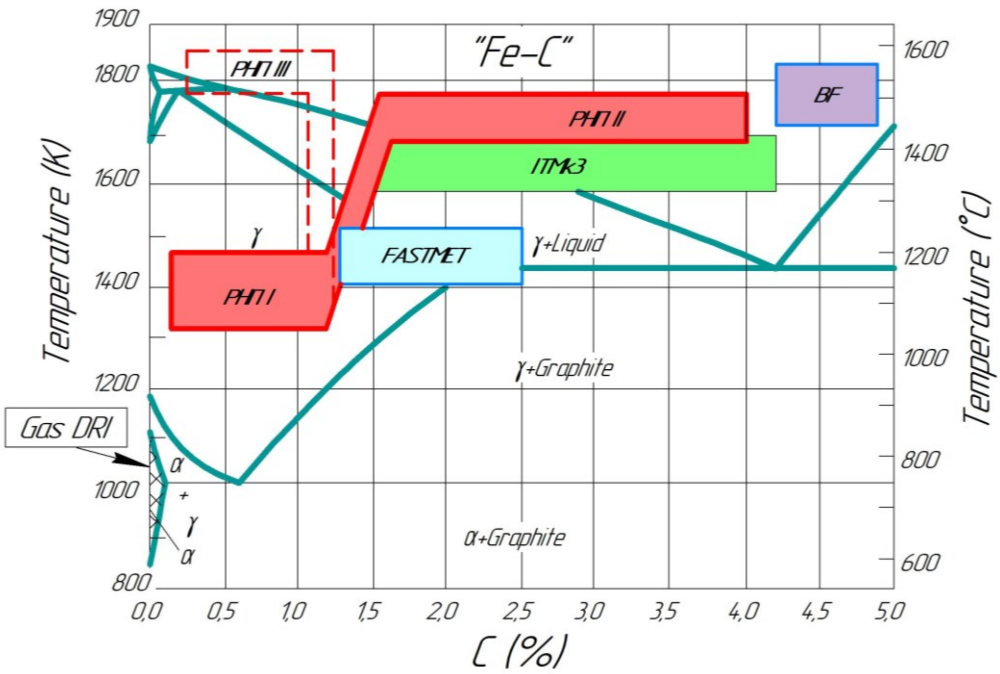


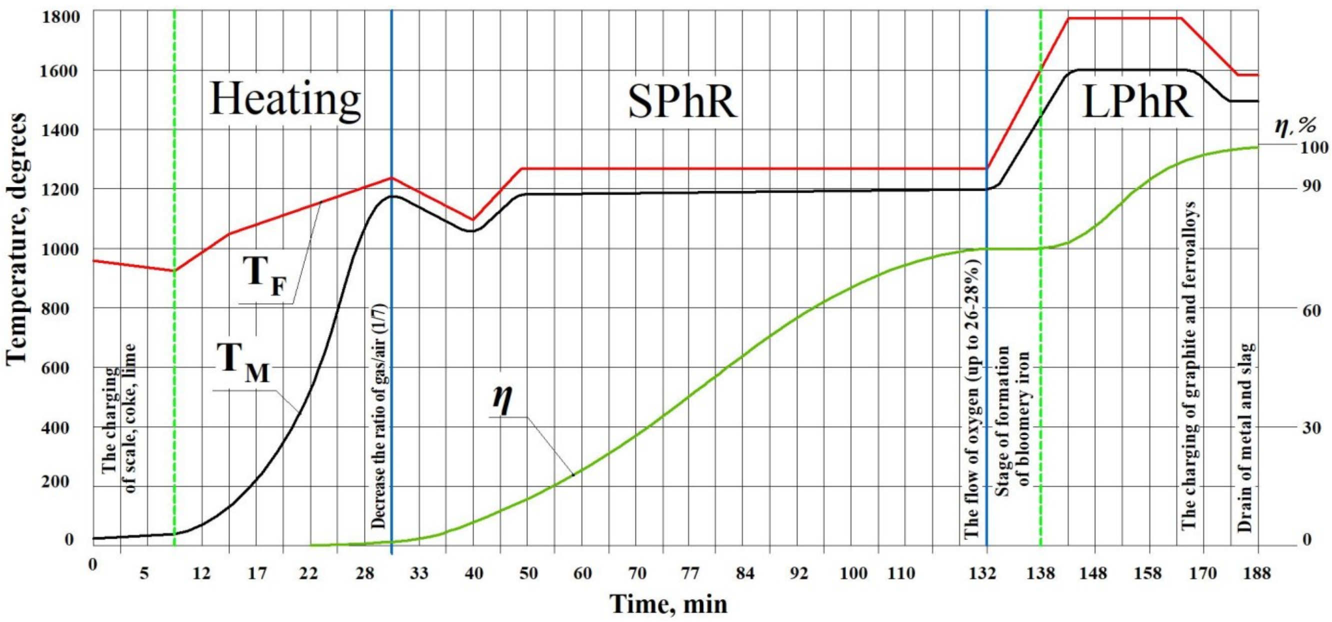
Fig. 3.– Technological interval of producing iron carbon alloys in RTF.

Technology of processing oxide iron-bearing wastes in RTF may be divided conditionally into two main stages, realized successively and continuously in one facility:

I – solid-phase reduction of iron oxides in recovering atmosphere (may be reached by gas burning with oxygen deficiency α = 0,6 – 0,7) with reducing agent (undersized coke, lignin, crushed electrodes, etc.) at 1000-12000 ºC. Such long process taking about 2,5-3,0 hours depending on oxidation level of the original material. Metallization degree at the end of solid-phase reduction is 70-80 %.

II – smelting, final liquid-phase reduction, melt carbonization, if necessary; equalizing till boiling stops and mold casting; or melt ladle pouring and transfer for chemical composition adjustment into electric furnace (duplex-process). Furnace temperature at melting rises up to 1700-1800ºC, which is achieved by oxygen enrichment up to the general content of (27-29 %). The duration of the above stage is 30-50 minutes.

Specific temperature – time recycling mode of scale is presented in Fig.4.



T_F – furnace temperature; T_M – materials temperature; η – metallization rate

Fig. 4. – Mode of scale reduction melting in RTF.

The process of recycling of unoxidized metal wastes (iron turnings, metal dust, fine scrap) in RTF is limited to remelting. Metal oxidation is prevented thanks to high heating speed (60-80 K/min) and furnace reducing atmosphere. At melting 5-7 % contaminated iron turnings (moisture, oils, non-organic compounds) metal field made up 95-93 %. At oily turnings melting specific fuel (natural gas) consumption decreases.

Metal, produced in RTF, depending on the original task, my be casted into ingots (pig) with further use as burden in traditional melting facilities, or transmitted to electric furnaces for adjusting chemical composition in accordance with branded alloys or for its bringing up to the set composition directly in RTF.

Besides recycling of iron-bearing wastes, technological processes and rotary furnaces for processing disperse aluminum, copper and lead-bearing wastes have been developed and introduced into production.

In total 8 technological recycling processes and 15 rotary facilities have been developed and introduced into production at 12 Plans in the Republic of Belarus and in Russia (some of the facilities are presented in Fig.5).

a  *b*  *c* 

a – processing of iron turnings("Centrolit",City of Gomel, Belarus); *b* – lead recycling ("KPVR SPLAV", City of Riazan, Russia); *c* – recycling of iron scale and sludge ("BMZ", City of Zhlobin, Belarus)

Fig. 5. – Rotary furnaces for the recycling of dispersed metal waste.

Conclusion

For the first time in the world, the process of obtaining iron from oxides (oxide and multicomponent iron-containing wastes) with the output of metal (cast iron or steel) to 90% of the theoretically possible by continuous solid-liquid phase reduction in one unit (RTF) without overloads and stops at intensive mode with rates exceeding the recovery rates in known SPhR-processes, and with lower specific energy costs than in the LPhR-processes. The new process allows for batch processing of materials, which makes it possible to carry out decentralized low-tonnage recycling of disperse metal waste without their preliminary preparation directly at machine-building, metallurgical and metalworking enterprises - sources of this waste.

The introduction of the developed technology and equipment allows creating a new raw material base for foundry production, reducing dependence on primary charge materials, organizing the non-waste turnover of metals in industry, eliminating accumulated metal waste, using waste of solid carbonaceous materials, thus obtaining significant economic and environmental benefits.

Literature

1. Yusfin Yu.S., Himmelfarb A.A, Pashkov N.F. New processes of metal production (iron metallurgy). (Novye protsessy polucheniya metalla (metallurgiya zheleza)). M.: Metallurgy, 1994. 320 p.
2. Rovin S.L. Recycling metal waste in rotary furnaces. (Retsikling metallootkhodov v rotatsionnykh pechakh) Minsk: BNTU, 2015. 382 p.
3. Tulin N.A., Kudryavtsev V.S. and others. Development of non-coke metallurgy (Razvitiye beskoksovoy metallurgii) / Ed. N.A.Tulina, K.M. Mayer. M .: Metallurgy, 1987. 328 p.
4. Bondarenko B.I., Shapovalov V.A, Garmash N.I. Theory and technology of non-coke metallurgy (Teoriya i tekhnologiya beskoksovoy metallurgii) / Pod. red. B.I.Bondarenko. K.: Naukova Dumka, 2003. 506 p.
5. Die Reduktion der Eisenerse. L. von Bogdandy, H-J. Engel / - Verlag Stahleisen mbH, Dusseldorf, 1967. 520 p.