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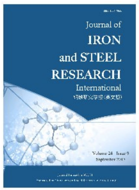

Thermal and chemical analysis of massive use of hot briquetted iron inside basic oxygen furnace

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ABSTRACT

The integrated steelmaking cycle based on the blast furnace-basic oxygen furnace (BOF) route plays an important role in the production of plain and ultra-low carbon steel, especially for deep drawing operations. BOF steelmaking is based on the conversion of cast iron in steel by impinging oxygen on the metal bath at supersonic speed. In order to avoid the addition of detrimental chemical elements owing to the introduction of uncontrolled scrap and in order to decrease environmental impact caused by the intensive use of coke for the production of cast iron, HBI (hot briquetted iron) can be used as a source of metal and a fraction of cast iron. Forty industrial experimental tests were performed to evaluate the viability of the use of HBI in BOF. The experimental campaign was supported by a thermal prediction model and realized through the estimation of the oxidation enthalpy. Furthermore, the process was thermodynamically analyzed based on oxygen potentials using the off-gas composition and the bath temperature evolution during the conversion as reference data.

Symbol List

$c_{p,\mathrm{SoI}}$—Specific heat of iron at solid state, $\mathrm{kJ \cdot kg^{-1} \cdot K^{-1}}$;
$c_{p,\mathrm{LiI}}$—Specific heat of iron at liquid state, $\mathrm{kJ \cdot kg^{-1} \cdot K^{-1}}$;
f_{ri}—Element fraction;
$\Delta H_{\mathrm{thTOT}}$—Total enthalpy of formation, $\mathrm{MJ \cdot kmol^{-1}}$;
ΔH_{CO}—Enthalpy of formation of carbon monoxide, $\mathrm{MJ \cdot kmol^{-1}}$;
ΔH_{FeO}—Enthalpy of formation of ferrous oxide, $\mathrm{MJ \cdot kmol^{-1}}$;
ΔH_{MnO}—Enthalpy of formation of manganese oxide, $\mathrm{MJ \cdot kmol^{-1}}$;
$\Delta H_{\mathrm{P_2O_5}}$—Enthalpy of formation of phosphorus oxide, $\mathrm{MJ \cdot kmol^{-1}}$;
$\Delta H_{\mathrm{SiO_2}}$—Enthalpy of formation of silica, $\mathrm{MJ \cdot kmol^{-1}}$;
$\Delta H'_{\mathrm{castiron}}$—Heat transferred to cast iron, MJ;
$\Delta H'_{\mathrm{solidcharge}}$—Heat used in melting solid charge, MJ;
$\Delta H''$—Heat transferred to metal bath, MJ;
ΔH_i—Enthalpy of formation of compound i;
$\mathrm{IN_{HBI}}$—Input ratio of HBI, %;
$\mathrm{IN_{PI}}$—Input ratio of pig iron, %;
$\mathrm{IN_{SC}}$—Input ratio of scrap, %;
$\mathrm{ip_{HBI}}$—Input of HBI, t;
$\mathrm{ip_{PI}}$—Input of pig iron, t;
$\mathrm{ip_{SC}}$—Input of solid scrap, t;
$\mathrm{ip_{TOT}}$—Total input of charge, t;
Δm_{C}—Oxidized carbon amount, kg;
Δm_{Mn}—Oxidized manganese amount, kg;
Δm_{P}—Oxidized phosphorus amount, kg;
Δm_{Si}—Oxidized silicon amount, kg;
m_{cc}—Cold charge scrap mass, kg;
m_{ci}—Cast iron charge mass, kg;
m_{in}—Initial metallic charge;
m_{ts}—Tapped steel mass, kg;
M_{Fe}—Molar mass of iron, $\mathrm{kg \cdot kmol^{-1}}$;
p—Partial pressure;
q_{i}—Actual mass charged, t;
Q_{i}—Heat from oxidation, MJ;
r—Heat fraction;
t—Time, s;
T—Temperature, ℃;
T_{amb}—Ambient temperature, ℃;
T_{EP}—End-point temperature, ℃;
T_{IB}—In-blow temperature, ℃;
T_{load}—Cast iron loading temperature, ℃;
T_{m}—Furnace regime temperature, ℃;
T_0—Initial temperature, ℃;
Δy_{Fe}—Oxidized iron amount, kmol;
$y_{\mathrm{O2\_}i}$—Moles of oxygen in compound i, kmol;
yi—Yield;
yi_{coe}—Yield coefficient;

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yi_{con}—Yield conversion;

λ_{Fe}—Fusion latent heat of iron, kJ · kg^{-1};

τ—Time constant, s.

1. Introduction

In 2015, the global steel production obtained from blast furnace (BF) and electric arc furnace (EAF) cycles amounted to 1.11 billion tons[1]. The demand for large quantities of high quality steel encouraged the creation of integrated steel mills based on the coupling of blast furnaces and basic oxygen furnaces (BOF). However, in recent years, environmental requirements have become more stringent and the electric arc furnace turns out to be a good alternative to integrated plants. On the other hand, EAF cycles will never completely replace integrated steel[2-4].

The increase of the steel scrap and hot briquetted iron (HBI) used in the BF-BOF route reduces the greenhouse gases (GHG) emissions involved in this technological route and is applicable to the existing BF-BOF plants in a reasonable timescale[5,6]. Moreover, the increased scrap used in BOF does not require major changes in the steelmaking practices[7].

Furthermore, the increased availability and reduced cost of natural gas has prompted steelmakers to investigate the implementation of direct reduced iron (DRI) in their existing steelmaking operations to decrease operating costs and environmental impact. The addition of DRI in the blast furnace to increase the hot metal output and decrease the coke rate is well known[8,9]. Unfortunately, this option has economic merits only if the downstream equipment of the steel plant is able to process the additional iron units into cast or rolled steel[10,11].

HBI has also other benefits such as[12,13]:

(1) high bulk density, if compared to the usual morphologies of the steel scrap, thus implying savings in the volume taken up by the scrap;

(2) known and homogeneous chemical composition;

(3) minimum amount of undesired elements difficult to be controlled in the scrap charge, i.e., Cu, Ni, Cr, Mo, Sn, and Pb;

(4) high thermal conductivity allowing a fast dissolution within the converter;

(5) low tendency for re-oxidation in contact with fresh and/or salted water.

An experimental campaign was carried out in order to assess the possible increase of the cold charge loaded into the BOF in substitution of cast iron. This paper aims to maximize the ratio between the quantity of steel tapped from the converter and the charged cast iron, and to analyze the thermal evolution of the metal bath.

2. Experimental Procedure

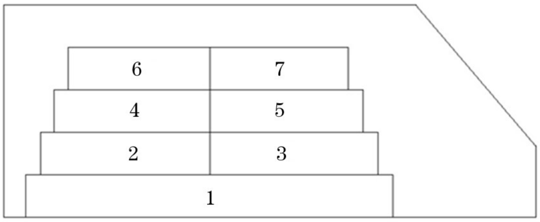
The planned experimental campaign considered forty heats in a BOF featured by an overall capacity of 315 t of medium tapped liquid steel corresponding to an overall charging capacity of 360 t.

The pre-reduced iron amount was progressively increased within the BOF (Table 1), starting from a quantity of 18 t of HBI up to 45 t of HBI, while the scrap amount was maintained at 45 t for all the heats observed (Table 1).

Table 1
Amount of HBI used in each heat

Number of tests	2	6	1	5	4	4	1	3	14
HBI/t	18	25	27	30	35	40	38	42	45

During the experimental campaign, the metallic charge was disposed in a specific charging case and ordered from bottom to top as described in Fig. 1.



1—Scrap from extrusion profiles or light scrap (slippery scrap); 2—Hot briquetted iron, direct reduced iron, granulated cast iron; 3—Heavy scrap from demolition; 4—Purchased ferrous scrap from demolition or light scrap; 5—Ladle funds; 6—Tundish waste; 7—Internal scrap.

Fig. 1. Scrap disposition inside a specific charging case.

The lime is charged directly into scrap case and the overall quantity ranges between 1.0% and 2.5% of the overall input charge and the contribution from mass flow and energetic point of view can be considered negligible.

The average chemical compositions of cast iron and HBI were measured (Table 2) in order to verify a homogeneous chemical composition of the metal charge introduced in the different observed industrial tests.

To optimize the analysis, the conversion process was divided in two observation periods[2,14]:

(1) "In-blow" (IB) from the blowing onset to the first blowing stop (to allow the bath chemical composition analysis)[15];

(2) "End-point" (EP) of the second blowing step after the stop.

The BOF conversion process generates a huge