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BLAST FURNACE PROCESS: IS THERE ANY ALTERNATIVE?[1]

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Abstract

Steel-making is globally based on hot metal refining in basic oxygen furnaces. At present and in perspective iron ore and coal remain the main primary materials for iron-making. Available processes of iron-making without a blast furnace are far behind the blast furnace process in terms of productivity and total through-out consumption of fuel for production of hot metal which includes the costs of coke and agglomerated raw materials production, hot blast and oxygen generation. Blast furnace process is the leader in terms of the amount of hot metal production with minimal production cost and in the near future can not only reserve the leading role but significantly reduce the cost for iron-making and the environmental impact. This possibility is related to the prospective use of self-reducing ore and coal briquettes made of concentrate and cheap coal-containing materials in blast furnaces. The process can also be further intensified by using oxygen and increasing the pressure within the furnace.

Key words: Blast furnace process; Efficiency; Total fuel rate; Productivity, Alternative processes; Ore and coal briquettes.

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1 INTRODUCTION

At present steel is mostly made from hot metal, its percentage in the metallic charge of BOF vessels is 75-95 %, and in EAFs at integrated plants – up to 30-35 %. According to forecasts, by the end of the 21st century steel output will exceed 2 billion tons, hot metal output – 1.3 billion tons [1]. A major part of steel is made in BOF vessels, and it does not seem probable that this steelmaking process will be replaced by some other technology in the foreseeable future. Therefore, the global steel production in forthcoming decades will still be based on hot metal, and its main raw materials will still be iron ore and coal.

Practically all hot metal (99 %) is currently produced in blast furnaces. The efficiency of heat and mass transfer in modern furnaces using quality coke and processed iron ore materials and equipped with efficient devices for monitoring and control of their distribution along the furnace radius is at least 95% of theoretical maximum [2,3]. There are known cases when some furnaces achieved 100% of mass transfer efficiency based on monthly operation. In terms of productivity and specific energy consumption for ironmaking, BF process shows significantly higher results than other existing alternative ironmaking processes using iron ore or iron-ore pellets.

However, at present sinter, coke and iron productions account for more than a half of total energy consumption and more than a half of all environmental pollutants at integrated plants.

Due to increasingly stringent environmental requirements as well as diminishing resources of natural reserves, especially cocking coals and high quality iron ores, metallurgists seek new, more economic and environmentally friendly processes to produce iron from ore and coal.

So the question is – can such a technology emerge in the near future that could successfully compete with the existing sinter-coke-BF iron production technology in terms of energy consumption, productivity and hazardous emissions?

2 DISCUSSION

Currently the steel plants in South Africa, Korea and India use well-known 2-stage direct ironmaking processes using processed iron ore materials (3 Corex-2000 modules and 2 Corex-3000 modules) and fine iron ore (2 Finex modules with the capacity of 1.5 and 2.0 mtpa) [4].

Since 2008 a Hismelt facility has been in trial operation in Australia, but it has not yet achieved the design productivity (800 thousand tons per year); this process involves iron ore preheating and therefore it is also a 2-stage process.

At the end of 2011, a Technored line with 500 thousand tpa capacity was being commissioned in Brazil.

The construction of a mini-mill producing hot metal in a ROMELT line with 200 thousand tpa capacity is about to be completed in Myanmar. It is expected to be started up this year.

Though there can be different forecasts for ironmaking process routes in this century, experts do not doubt that the hot metal oxygen refining process for steelmaking will still be used. As to alternative ironmaking processes development prospects and gradual replacement of blast furnace process by them, the forecasts are more than conservative. In the 90's there were forecasts that by 2010 the share of hot metal produced by Corex, Finex, DIOS and other processes would grow up to 15%, but it never happened. The actual share of such hot metal in 2010 just slightly

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exceeded 0.6 % [2,3]. Moreover, though at the time of Corex and Finex commercialization, it was stated that these processes are coke-free, they still use coke, however, in smaller quantities than the BF process.

TECHNORED and ROMELT, the actually coke-free liquid-phase reduction processes, have not yet exceeded 0.05% of globally produced hot metal. As to the prospects of the development of these processes, quite opposite statements are presented and discussed.

Thus, the analytical research of Wei-Kao Lu, professor of McMaster University, and his colleagues shows that theoretically minimal coal consumption in liquid-phase reduction processes cannot be lower than 650 kg/t of hot metal [5], which is much higher that the coal (as coke and PCI) consumption level achieved in blast furnaces. It means that in terms of energy consumption these processes cannot compete with blast furnace technology.

A.K. Tarakanov with colleagues' states that liquid-phase reduction processes that are not used commercially, and not two-stage Corex and Finex processes, can become an alternative to blast furnace process if the issue of efficient waste gas recovery is solved [6]. They think that the main advantage of the liquid-phase reduction technology is not its versatility but cheaper ironmaking as compared to BF process, thermal coal gasification with hot reduction gas generation, slag clinker production with preset composition.

However, a number of specialists think that the sinter-coke-BF process cycle still has some capacity for improvement of productivity, as well as energy and environmental characteristics. The author of this paper shares the same point of view. There are reserves and technical possibilities to significantly improve the technical and economic parameters of BF operation.

Maarten Geerdes and colleagues think that it can be possible if oxygen concentration in the blast is doubled, and PCI rate is increased up to 300 kg/t and more [7]. In this way it is possible to significantly increase the process intensity, BF specific productivity and reduce hot metal cost. However, it can be used only if high-quality coke with optimum fraction size and high CSR and CRI is used in blast furnaces. Moreover, this method turns a blast furnace into a power-and-ironmaking facility that produces not only hot metal but also gas with calorific value twice higher than that of normal BF gas – that is why it is necessary to solve the issue of using this gas energy efficiently.

The alternative way to intensify the process and to boost BF productivity would be to increase top gas pressure by 1.5-2.0 times, which requires a corresponding reinforcement of the whole BF blast duct system and using higher-power blowers [8]. Operational practice of HYL facilities shows that this is a feasible way. However it does not allow reducing energy consumption for ironmaking.

The new way to increase BF process energy efficiency is to use "self-reducing" ore-coal briquettes made of iron-ore concentrate and cheap thermal coal (or other carbon-containing material) instead of sinter in the BF burden. This fluxed BF burden component produced by "cold" method not involving fuel combustion can reduce energy consumption as well as hot metal cost, as it reduces coke consumption for ironmaking. Carbon contained in briquettes is used for direct Fe reduction instead of coke carbon. When such briquettes are used for ironmaking, the total fuel rate is also reduced due to the fact that the briquettes are produced without fuel combustion, and fuel rate for coke production is also reduced. In 2003 NLMK was the first company in the world to successfully carry out a commercial trial of "self-

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reducing" briquettes made of iron ore concentrate and coke fines in the amount up to 302 kg/t of hot metal [9, 10].

The large-scale application of this new burden component in the BF process becomes feasible as a high-output and cost-effective technology for briquetting particulates by hard extrusion using mineral binder has appeared in the market of metallurgical pelletizing technologies. This technology is already being used to produce briquettes using metallurgical sludges and ore fines, and self-reducing Fe- and C-containing briquettes (BREX) produced in this way are successfully used. BREXes are characterized by sizes optimal for the blast furnace process (25-30 mm dia, 40-50 mm long), as well as favorably high cold and hot strength and reducibility. BREXes produced from the combination of steelmaking and blast furnace sludges (70%) and iron ore fines (30%) have been used in small blast furnaces of India quite successfully, their share in a two-component burden (BREXes + high-grade ore) being as high as 80% now. This practical experience of using BREXes and the high-capacity technology of their production certainly allows us to speak with certainty of the potential gradual, and at least partial, switch from sintering to the new environmentally clean technology of pelletizing iron ore fines and concentrates.

The effect of BREXes in the blast furnace process has been evaluated by computer simulation of blast furnace operation using sinter and pellets (conventional burden) and using BREXes and pellets. Top gas pressure, blast composition and temperature, and PC injection rate were similar. Analyses of sinter, pellets and BREXes are shown in Table 1.

Table 1. Chemical composition of BF burden components

Components	Fe	FeO	SiO_2	CaO	MgO	Al_2O_3	C
Sinter	58.5	13.48	7.31	8.35	1.35	0.72	-
Pellets	64.4	1.51	7.04	0.22	0.45	0.32	-
BREXes*	50.17	21.9	7.62	8.97	0.54	0.91	8.35

Notes:*Component composition of BREXes: iron ore concentrate – 79 %; coal – 12 %; cement+bentonite – 9 %; lime - 4 %.

Blast furnace parameters obtained by means of a computer simulation for 4 variants of burden and dynamic gas conditions are shown in Table 2.

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Table 2. Conditions and estimated results of blast furnace operation by variants

	Blast furnace conditions and performance values	Basic variant	Variant 1 (BREX)	Variant 2 (O_2=60%)	Variant 3 (P=550 kPa)
1.	Sinter rate, kg/t, (%)	1152, (70.5)	-	1151, (70.5)	1151, (70.5)
2.	Pellets rate, kg/t, (%)	482, (29.5)	691, (40)	482, (29.5)	482, (29.5)
3.	BREX rate, kg/t, (%)	-	1037, (60)	-	-
4.	Coke rate, kg/t	332	227	242	328
5.	Natural gas rate, m^3/t	20	20	20	20
6.	PCI rate, kg/t	150	150	300	150
7.	Fe in burden, %	59.34	56.15	59.34	59.34
8.	Blast temperature, °C	1200	1200	600*	1200
9.	O_2 in blast, %	26	26	60*	26
10.	O_2 flow rate, m^3/t	47	47	190	46
11.	Theoretical combustion temperature, ˚C	2126	2132	2133	2119
12.	Blast flow rate, m^3/t	889	896	464	874
13.	Top pressure (absolute value), kPa	300	300	300	550
14.	Top gas heat value, MJ/m^3	3.57	3.78	5.88	3.57
15.	Gas utilization factor, %	50.3	47.5	47.74	50.47
16.	Degree of direct reduction, %	38.6	50.8	25.9	39.0
17.	Slag output, kg/t	300	297	297	300
18.	Slag basicity	1.05	1.05	1.07	1.06
19.	Production, t/m^2·day	69.0	67.0	86.8	87.5
20.	∑ T1, kg reference fuel/t	472	472	503	468
21.	∑ T2, kg reference fuel/t	608	572	655	603
22.	∑ T3, kg reference fuel/t	428	381	422	425

Notes: * Using high-temperature blast enriched with oxygen up to 30°C and cold oxygen.

∑T1 – total fuel rate (Coke +PC + natural gas); ∑T2 – total through fuel rate**; ∑T3 – total through fuel rate** excluding top gas; **Includes the rate of process fuel used for the process itself and fuel used in the production of coke, pelletized iron ore raw material, blast, and oxygen consumed in this technological process. This criterion is indicative of the energy consumption of the process, as well as of the quantity of relevant greenhouse gas (CO2) emissions. The specific fuel rate figures related to the production of coke, sinter, pellets, lime, cement, blast and oxygen are reference figures and actual data of NLMK.

It is evident that the maximum total through fuel rate is achieved when the furnace runs with conventional burden, but with oxygen enrichment up to 60% and maximum PCI rate (300 kg/t). Furnace capacity is also the highest in this variant.

The minimum through fuel rate occurs with burden containing BREX and pellets.

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The through fuel rate excluding top gas is practically the same in all variants of BF operation with similar burden (difference is within 1.5-2%).

The simulation has demonstrated that BF running with burden containing self-reducing BREXes (60%) compared to burden containing sinter (70.5%) will allow a 30% coke reduction and a 10% reduction of total through fuel rate accompanied by a 3% decrease of capacity.

The advantage of blast furnace operation with top gas pressure increased up to 450 kPa over running on oxygen-enriched blast (up to 60%) at a high (up to 300 kg/t) PCI rate is a lower (by 8%) total through fuel rate at a practically similar capacity.

The same method has been used to calculate total through fuel rate for Corex, Finex and Hismelt processes based on published figures [4,11-13] of fuel and oxygen rates and blast parameters (Table 3) for the purpose of comparison with the given BF process variants. The output and calorific value of exhaust (outbound) gas in those processes have been calculated by the balances of carbon, injected oxygen, blast and oxygen in iron ore burden. Unfortunately, the data on coal and oxygen consumption in Technored ironmaking process were not available, and we could not evaluate the relevant energy consumption. However we hope that optimistic values of this parameter can be reached if ore-coal briquettes are used as a main burden component.

Table 3. Total through fuel rate in case various ironmaking processes are used

Parameters	Basic variant	Variant 1 (BREX)	Variant 2 (O_2 = 60%)	Variant 3 (P=550 kPa)	Corex process	Finex process	Hismelt process
Coke rate, kg/t	332	227	242	328	100	60	-
Coal rate, kg/t	150	150	300	150	770	870	750
O_2 flow rate, m^3/t	47	47	190	46	455	520	245
∑T2, kg reference fuel/t	608	541	655	603	846	898	693
∑T3, kg reference fuel/t	428	350	422	425	684	680	508

Even though calculations are approximate (due to the lack of precise data on iron ore material composition (we assumed Fe content as 64%) and coal composition, on outbound gas generation and calorific value in these processes), the results provide strong evidence of the blast furnace process superiority over dual-stage processes Corex and Finex in terms of energy. Also, the single-stage liquid-phase reduction Hismelt process is less energy-consuming as compared to dual-stage ironmaking.

According to Joseph Vehec and Wei-Kao Lu [14], a technology combining sponge iron production from ore-coal pellets by PSH (The Paired Straight Hearth)

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process and ironmaking in a coal-oxygen converter with the use of pre-reduced pellets can be a competitor of the coke-BF process in terms of fuel rate for ironmaking. PSH process is carried out in two parallel tunnel furnaces with movable hearth. According to the calculation, fuel rate for ironmaking in line with this technology is 30% lower than in most efficient blast furnaces [14] due to 100% utilization of carbon energy (first, for Fe reduction and then for heat generation during full combustion of CO to CO_2). Ironmaking in a coal-oxygen converter using hot pre-reduced pellets is a high-intensity process. Due to this fact, as well as low design fuel rate, the design engineers can optimistically declare this technology as a possible alternative for the coke-BF process. However, so far this process is still at the laboratory research stage, and, as the experience shows, in iron and steel industry the path from laboratory research to a commercial line can take a few decades.

3 CONCLUSIONS

Mass production of steel in the 21st century is based on hot metal, and the blast furnace process remains the dominant technology. The existing alternative ironmaking processes – Corex and Finex – require higher total fuel rate. According to the analytical research of Prof. Wei-Kao Lu (Canada) the theoretical minimum fuel (coal) rate for ironmaking by means of a liquid-phase process cannot be 650 kg/t, which exceeds the fuel rates of the best blast furnaces. As per calculations, a lower fuel rate (by 30%) for ironmaking without coke can be achieved using a two-stage PSH process that is at the stage of laboratory research now. The process includes pre-reduction of ore-coal pellets in tunnel furnaces with movable hearth and ironmaking in a coal-oxygen converter.

If sinter is replaced in blast furnaces by state-of-the-art ore-coal briquettes (BREX), due to high energy intensity the BF process will dominate in iron extractive metallurgy for many decades and will significantly mitigate the environmental impact.

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