REFERENCES

1. *Rudenko O. G., Shchamraev A. A.* The development of the neural network of the monitoring of sodium carbonate production. / Bulletin KhGTU № 1(19), 2004. — p. 366–370.
2. *Golubev V. O.* The research of the process of metallurgical limestone kilning //The Proceedings of the Mining Institute, 2006. V. 169. P. 101–103.
3. Methods of robust, neural and fuzzy, adaptive control: textbook / ed. N. D. Egupova; the 2-nd edition. — M.: Publishing house of MGTU named after N. E. Bauman, 2002. — 744 p.
4. *Tsaregorodtsev V. G.* Optimization of data reduction for the testing neural network: optimum criterion // Materials of XIV International Neurocybernetics Conference, Rostov-on-Don, 2005. V. 2. — P. 64–67.
5. *Krisilov V. A., Chumichkin K. V., Kondratyuk A. V.* The representation of the initial data in problems of neural network prediction // Scientific session of MIFI-2003. National scientific and technical conference «Neural IT — 2003»: the Collection of proceedings in 2 parts. P. 1. M:MIFI, 2003, p. 184–191.
6. *Khaikin, S.* Neural networks: complete course, the 2-nd edition: English version translat. — M.: Publishing house "Williams", 2008. — 1104 p.

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Small-volume blast-furnaces — the future of blast-furnace practice?

New structural scheme of ferrous metallurgy

In the past century, the ferrous metallurgy developed towards constructing large volume aggregates. Outdated and small blast-furnaces were replaced by large volume blast-furnaces. The traditional pig-iron making technology remains the fundamental technique for various grades steel smelting and metal products manufacture. At the present time about 70 % of the world steel production is based on primary metal production, obtained by traditional technology. At least 95 % of the world pig-iron is obtained in blast-furnaces. That fact proves that blast-furnaces play a crucial role in ferrous metallurgy.

Under these conditions it is necessary to overestimate the use perspectiveness of large volume blast-furnaces.

The USSR was the world leader in large-volume blast-furnace manufacture. In the latter half of the past century blast furnaces with the working volume of 1386, 1513, 1719, 2002, 2300, 2700, 3200, 5014, 5580 m3 were manufactured. These aggregates increased the productivity and therefore proved the economic benefit of the blast-furnace working-volume increase. The in-depth analysis was carried out piecewise so that the existing political system and the industrial development course (at that time) would not be doubted.

Meanwhile, there are some disamenities of blast-furnace volume increase. These are:

1. Large-volume blast furnaces operate only when high quality burden material is used, therefore when operating large-volume blast furnaces the burden material preparation costs increase.

2. Considering the blast-furnace height limitations, the volume increase was generally performed by aggregate lateral dimensions increase. Under these conditions the basic blast-furnaces processes development was hindered along the furnace cross-section which eventually led to cast iron composition when tapped from different tap holes.

3. The lateral dimension increase led to oxidation zone decrease relative to furnace hearth radius. That led to coke packing performance difficulties. In 1980's engineers once again started to use the term "dead man".

4. Some difficulties occurred with facility management on integrated iron-and-steel works. Accidental and emergency shut-downs of large-volume blast furnaces could easily shut down the utilities and pig iron consumers since large-volume blast furnaces excluded the possibility of a maneuver available when using a small-volume blast furnaces. Along with that, large burden masses that were processed by blast-furnaces caused railway service functioning difficulties.

5. The environmental restrictions led to the end of large-volume blast-furnaces domination era.

It is widely known, that the major drawback of metallurgical branch (in terms of environmental impact) is its high concentration ratio. Comparing to other industrial branches, metallurgical branch is defined by high concentration per area unit of a metallurgical region. Based on environmental conditions and population health status, it is advisable to utilize 5 blast furnaces with the working-volume of 1000 m^3 spaced far apart than one 5000 m^3 furnace.

6. The world raw material market formation changes the views on metallurgical branch. For Third World Countries along with separate regions of large countries it is not necessary to produce large quantities of primary metal therefore it is not necessary to construct large volume aggregates.

7. In most cases, small volume blast furnaces have better working data (by energy resources consumption) and are more maneuverable in terms of manufactured products range. Finally the recycling process of technogenic and sanitary waste takes place primarily in small volume metallurgical aggregates.

The increased number of mini-mills along with micro-metallurgy affects the problem of blast furnace volume solution.

Steel on mini-mills is generally obtained in EAF (DC or AC). The raw materials generally consist of steel scrap, and direct reduced iron (sponge iron and prereduced iron pellets). Historically, the steel manufacture in EAF is associated with low quality steel manufacture for long-length manufactured articles. Nowadays, mini-mills (in connection with modern metallurgical technology of thin slabs casting) proceed to high-quality steel production.

As it is known, in EAF process the common iron sources are: steel scrap, sponge iron (pellets) and hot briquetted sponge iron. For high-grade steel manufacture, and for hot-rolled steel strips it is necessary to use high-quality steel scrap.

Alongside, liquid conversion pig iron offers several advantages over high grade steel scrap and over scrap substitutes. Lack of unwanted impurities such as copper, tin, chrome and nickel, guarantees constant high quality of metal products.

Some other advantages of liquid conversion pig iron (when compared to steel scrap) are: high heat content and "chemical heat" of carbon and silicon that ranges from about 60% of liquid iron sensible heat. Hence, when using liquid iron, the consumption of electric energy in steel industry decreases.

According to [1], when using 40 % of conversion pig iron the EAF productivity increases by 30 % and the energy usage decreases by 36 %. The tapping rate increases and the electrode consumption decreases.

Modern pig-iron production concepts

In 1990's the demand in cheap liquid conversion iron and solid cold pig-iron that was smelted in comparatively small quantities for numerous mini-mills led to the development of pig iron smelting practice in small volume shaft furnaces.

The demand for small quantities of liquid conversion pig-iron led to the reduction of smelting process development. The traditional blast-furnace process quickly adapted to this demand. According to modern trends [2–5], small-volume blast furnaces (that were constructed for mini-mills needs) are divided into following categories (Tab. 1).

Table 1. International small volume blast furnace classification

Aggregate type and international abbreviation	Working volume, m^3	Productivity, t/day
Compact BF (CBF)	500–1500	1000–4000
Mini BF (MBF)	100–500	300–1000
Micro BF	Up to 100	Less then 300

The smelting process in cupola furnace is also considered to be competitive. Modern cupola furnaces with hot blast produce about 100 t/hour (i.e. up to 2500 tons of liquid iron /day). Furthermore there were numerous research works on the new technology of cupola furnaces smelting by using oxygen enriched blast, and obtaining pig iron from various ferrous waste metal. As a result, few new metallurgical processes such as OxiCup, MR-OCF, KSK и Star originated:

— OxiCup or "oxygen cupola furnace" works on oxygen-rich blast;

— MR-OCF (Multirole-oxygen Cupola Furnace) and KSK (Kreislaufgas-Sauersoff-Kupolofen) – cupola furnaces with a gas recirculation system for complete silty material recycling process, that is injected trough tuyeres;

— Star — cupola furnace with double-level tuyere injection system for steel smelting, rolling and pickling dusts alongside with slimes in hot blast stream.

At the Atlanta (US) conference that took place in November 1999 [4] "Mini-mills with complete cycle in the new millennium" it was mentioned that under modern circumstances the competitive ability of metallurgical enterprises will be defined by raw material consumption and product nomenclature. For competitive ability it is necessary to have at least 5 shaft furnaces of different efficiency.

In particular the transition to primary metal production by using at least 2 CBF or MBF, and at least 2 cupola furnaces with different efficiency was discussed. In such a manner, one may state that the prevailing technology in the past 15 years was the development of pig-iron obtainment in small volume blast furnaces and cupola furnaces. Some specialists believe, that this tendency will be prevailing for the next 50 years.

MBF usage experience

New generation small-volume shaft furnaces are mostly found in Brazil, India, Indonesia and China. In china (2003), BF with the working volume of less then 500 m^3 produced about 30 Mtpa of pig iron (i.e. over 20% of all the pig-iron produced in the country). Table 2 shows the number of operating MBFs in various countries with the working volume ranging from 100 to 500 m^3. It should be noted that not all the small volume furnaces are registered. Therefore table 2 is incomplete. Among the mentioned blast furnaces over 400 are simply traditional small-volume blast furnaces. An MBF, which can be viewed, in some way, as a miniature and modified version of a conventional large blast furnace, has a few additional characteristics features known for its simplicity and economy. These features allow to obtain a competitive commercial pig iron [7].

The world leader in MBF and CBF construction is SMS Demag company. In the past 10 years the company constructed over 20 MBF in Brazil, India and Indonesia. 5 furnaces will be built during this year. These furnaces produce commercial pig-iron on nonintegrated steel works, or produce liquid conversion iron for mini-mills needs on integrated steel works based on basic oxygen converter or EAF. The MBFs that were built during the past 15 years generally have a working volume ranging from 100–250 m^3 with an average productivity of 2.2 t/m^3 as it is shown in Table 3.

Table 2. Foreign MBFs with the working volume of less than 500 m^3

Countries	Number of furnaces	Comments
China	over 250	Over 20% of all the pig iron produced in the country in MBFs with the working volume of less than 500 m^3.
Brazil	160	136 MBFs produce commercial cold pig iron, 24 MBFs work on a full cycle plants (including 5 furnaces built by SMS Demag)
India	21	All furnaces were commissioned after the year 1990 (including 15 SMS Demag furnaces)
Indonesia	10	
Vietnam, Paraguay, Poland, Turkey, Ukraine, France	2–3	
Argentina, Bosnia, Hungary, Peru, Tunis, Japan	1	

The working height of a MBF is 14–17 m, the feeding installation is a traditional biconical apparatus with a batch hopper. The usage of dice coal and coke with a short range of grain-size composition provides good burden distribution without complicated top charging equipment.

Compact metallic blast preheaters are used for steady, easily controlled temperature, ranging from 650–900 ^oC. High-grade, 62 % dense alumina refractories are employed for the hearth, base and lower stacks of the stacks of the furnace and 45 % dense alumina bricks in the middle and upper stacks to assure a comparatively low specific refractory cost in comparison with conventional blast furnaces. Copper plates and an expensive water circuit are not required for furnace shell cooling [7].

Taking all the necessary infrastructure into the account, relative capital costs for CBF and MBF are make about 100–120 $/tpa, depending on the country, facility quality, degree of mechanization and automatization etc. The capital expenditures for MBF are 50 % less when compared to traditional blast furnaces.

The prime advantage of an MBF is a wide range of raw materials. MBF can utilize coke with low strength index. Also MBF uses raw-materials with grain size ranging from 8 to 15 mm (Midwest plant, India). The coke ash content ranges from 12 to 18 % and reaches its maximum of 21 % (Midwest, India). Therefore, the raw-materials used in MBF are cheaper then regular raw materials used for traditional blast furnaces.

MBF can also use charcoal as a fuel material. In particular, Brazilian MBFs use only charcoal. The charcoal grain size ranges from 12–120 mm, with the 2–4 ash content (mass %).

The operating characteristics of a charcoal MBF is best described by a BF #2 at Belo-Horizonte plant. That particular blast furnace is operating by using 100 % charcoal with the grain size ranging from 10–25 mm, and on 100 % Chinese coke (with 15 % ash content (mass.)), and on various coke and charcoal combinations.

The iron-ore burden consists of: raw lump ore with 10–30 mm grain size alongside with hematite ore (6–12 mm), and pellets ranging from 6–16 mm.

Compact blast furnace

Recently developed compact blast furnaces (CBF) are used especially for mini-mills needs [2, 3].

The basic CBF characteristics that lower the production costs are:

— Absence of tower construction typical for traditional blast furnaces (i. e. CBF is a “standing” blast furnace);

— CBF is equipped (from top to bottom) with copper and pig-iron with spheroid graphite coolers, combined with reverse water cooling system;

— Vertical burden charge conveyor;

— Compact cast house and air heaters;

— High degree of controlling system automatization.

The CBF furnace (build by SMS Demag) has a 8 m hearth diameter, and is used for 1 Mtpa production [2, 3].

CBF is equipped with conical charging equipment with mobile blast furnace throat plates. The cast house design is compact, since only one tap hole is used. CBF is equipped with changeable tapping launder. Oscillating launder could operate by using hydraulic, pneumatic, or electric driving system. Pig-iron ducts are plugged with lids that provide the required cast house dedusting. CBF includes a bin trestle that provides a non-stop CBF operation for at least 15 hours. CBF is also equipped with 2 regenerative air-heaters with inner combustion chambers. All CBF equipment is located within the rectangular area (115×145 m). The slag granulation and pulverized coal injection system alongside with fuel oil and other petroleum derivatives, and pig iron casting installations are also provided.

Modern charcoal smelting process

Today world’s largest commercial pig-iron exporter is Brazil [6]. Brazil exports about 4.8 Mtpa of commercial pig iron which exceeds 1/3 of worlds market. Hence, it is evident that Brazil specializes on commercial pig iron export since it contributes over 16 % of worlds commercial pig iron production.

Brazil has about 67 commercial pig-iron manufacturers that operate 123 blast-furnaces (Tab. 4). These small volume blast-furnaces produce about 1.5–12 thousand tons of pig-iron/month.

Brazil is the only country in the world that uses charcoal for operating its blast-furnaces for commercial cold pig iron production. Charcoal is obtained from saw-mill wastes and a biomass of eucalyptus forestation.

Table 3. MBF performance data

BF characteristics	Companies, BF								
	Brazil			India					Russian Federation
	MSA №2, Belu-Orizonte	Gerdau №1, Divinopolis	Sidersul №1, Ribas du Riu Pardu	Sesa Goa №1	Midwest №1, Shrikaku-lam	Kirlos Kar №2, Khospet	Usha Marti №1, Jumshed-pur	Kalyani №1, Khospet	Satkinskiy Metallurgical №1, Satka
Working volume, m^3	250	118	136	175	215	250	215	250	224
Type of smelted pig iron	Conver-sion pig iron	Conver-sion pig iron	Conver-sion pig iron/cast iron	cast iron	cast iron	cast iron	Conver-sion pig iron	Conver-sion pig iron	Conversion pig iron / cast iron
BOL	1986	1982	1990	1992	1993	1995	1994	1998	-
Optimal monthly average productivity, t/m^3.	2,83	2,20	2,28	1,60	1,21	1,82	2,26	2,10	1,35
Raw materials									
— solid fuel	charcoal	charcoal	charcoal	coke	coke	coke	coke	coke	coke
— grain size, mm	10–25	12–120	12–120	20–60	15–25	15–60	15–50	25–60	25–80
— ash content, % (mass.)	2	3	4	12	21	15	13	12	11,8
— iron-ore materials	Lump ore	Lump ore	Lump ore	Lump ore	Lump ore	Lump ore	Lump ore	Lump ore	agglomerate. — 40%, pellets. — 60%
— particle size, mm	6–32	9–25	9–25	10–30	10–30	10–30	8–30	6–30	10–30
— Fe, content % (mass.)	66,5	65,0	66,5	65,0	64,0	65,0	65,5	65,0	55,5/63,2
Blast temp., ^oC	800	750	700	800	750	780	760	750	825
Solid fuel consumption, kg/ton of pig iron	640	630	637	600	700	640	590	620	Conv.pig iron. — 575, cast iron. — 850 + NG 55 m^3

Table 4. Brazilian pig-iron manufacturers characteristics

Number of blast-furnaces per one company	Number of companies that have the given amount of blast-furnaces	Total monthly pig iron production by these companies, tons	Company part (%) in total pig-iron production volume	Pig iron monthly average production per blast-furnace, tons
1	31	194800	23,5	6284
2	25	364200	44	7284
3	5	91500	11,03	6100
4	5	150000	18,1	7500
7	1	28000	3.37	4000
Total: 123	67	828500	100	6736

According to Brazilian state laws, all companies that use charcoal must carry out a program on plantation reconstruction. Typical forest plantations include eucalyptus trees according to a seven-year cycle. Each ton of obtained seasoned wood is provided with a growing biomass of 6.8 tons of wood substance, roots, leaves that absorb CO_2 and provide the oxygen flow to the atmosphere.

According to some research works, the entire process (from planting trees to pig iron manufacture by using charcoal) removes about 1.1 tons of CO_2 from the atmosphere.

When using coke for pig iron manufacture there is about 1.8 tons of CO_2 released to the atmosphere. Hence, by using charcoal the CO_2 emission to the atmosphere is decreased by 2.9 t/t of pig iron.

As is widely known, charcoal (when compared to coke) has lower physical strength, and also increased strength index when directly reduced, and reactive capability. Therefore, blast-furnaces that operate on charcoal, have lower height and larger diameter when compared to coke-operating blast furnaces.

The distinguishing feature of charcoal blast-furnace smelting is low slag yield (120–150 kg/t of pig iron) and slag basicity ($(CaO+MgO)/SiO_2$) — 0,75–0,85. The charcoal consumption (depending on its humidity and silicon content in pig iron) ranges from 750–1000 kg/t of commercial pig iron.

Charcoal-obtained pig iron surpasses the quality of coke-obtained pig iron since it has lower sulfur and phosphorus content. Furthermore charcoal-obtained pig iron usually does not contain such microelements as titanium, chromium, and zinc that enter the traditional blast furnace with coke ash.

Blast-furnace process improvement in small-volume furnaces

According to some researchers and blast-furnace operators opinion, the blast-furnace productivity could be significantly raised under certain circumstances:

— Increase in injected additive agents while raising the oxygen content;

— Increase in raw-material metallurgical quality.

— It is supposed that the blast-furnace with the working volume of 600 m^3 could produce from 4 to 7 tons of cast iron/m^3·day while supplying 350–400 kg/t. of pig iron of pulverized coal fuel. The coke consumption — 200 kg/t. and an oxygen content of 60 % (vol.). Upon providing well-balanced correlation between process oxygen and injected additives, optimal temperature distribution in blast-furnace could be reached. Tuyere flux injection improves the slag-making conditions.

During the recent years, the technology of iron-bearing materials and fluxes injection (i. e. converter slag) is greatly emphasized.

Numerous research works show, that the blast-furnace flux injections leads to first slag basicity decrease, and increase in slag basicity in the upper part of the furnace hearth. Various materials' technology development injection (earlier charged by means of furnace throat) is important for small volume blast-furnaces. The technology helps to lower the softening-melting zone, increase the blast-furnace productivity and solve the problems with low coke strength and charcoal in coke packing.

Blast-furnace development prospects

The development strategy of various kinds of metallurgical manufacture should be connected with the world economic tendencies. Most important metallurgical tendencies are:

1. Drastic reduction (for some regions even total disappearance) of iron ore deposits. In the 20th century, it is impossible to ignore the presence of associated ore components in amounts exceeding 0.001 %. Hence, iron ores are now considered as complex raw-materials. The technology of extracting just one element (i. e. iron) reaches back. Therefore it is necessary to evaluate and minimize irrecoverable losses of associated elements. MBF has the capability of smelting process management.

2. The energy resources consumption was always the key feature of its quality characteristics. Experience shows that blast-furnaces with the working volume up to 1000 m^3 and the usage of modern constructive innovations help to lower the energy resources consumption when compared to regular blast-furnaces.

3. The global recycling will become the key element of the industrial manufacture. Technogenic raw-materials recycling in MBF has an advantage over large volume aggregates.

These facts allow to assume, that the future of pig iron production belongs to small-volume (up to 2000 m^3) blast-furnaces.

REFERENCES

1. *Shaiding K., Sherer S. V. G., Pfaiffer Kh. K.,* etc. Production development tendencies of conversion pig-iron in small volume blast furnaces // Ferrous metals, 2000, No. 10, p. 28–39.
2. *Reifer F., Gantenberg M., Bertling R., Shiber G.* CBF as a modern alternative for conversion pig-iron obtainment on mini-mill // Ferrous metals, 2000, No. 7, p. 18–23.
3. CBF — modern engineering solution for pig-iron obtainment // Foreign ferrous metals news // 2001, No. 4, p. 37–40.
4. Metallurgical plans in new millennium // Foreign ferrous metals news // 2001, No. 2, p. 36–38.
5. Blast-furnace pig-iron production development // Foreign ferrous metals news // 2001, No. 3, p. 41–46.
6. *Monteiro L. S.* Charcoal BF operation in Brazil // Foreign ferrous metals news // 2001, No. 1, p. 36–37.
7. Amit Chatterjee, Ramesh Singh, Banshidhar Pandey Metallics for Steelmaking — production and use, ISBN 81-7764-130-1, 732 p.