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Current situation and predictions further development of blast furnace technology

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ABSTRACT

Purpose: of the paper is to present analysis on main technological factors that determine blast furnace worldwide productivity in today's time and may probably influence it in the future.
Design/methodology/approach: to gain the purpose of the paper is based on the literature review of the proceedings of newest congresses and conferences on iron making technology. The review embraces manifold technical and technological changes in the area of the manufacture of iron in blast furnaces in most important regions of worldwide iron production. The prospects for future possible developments of blast furnace technology is presented, too.
Findings: of this analysis show that directions of development of blast furnace technologies is characterized by: an increase the overall productivity of blast furnaces, the increase in volume blast furnaces and extending the period for campaign work of blast furnaces, systematic improving the quality of blast furnace charge, controlling its distribution, the introduction of coal dust injection and modernization of the equipments. Moreover, some specific researches were carried out e.g. a new process granulation for the control of melting materials, hybrid bonding iron ore of inferior quality, decreasing CO2 emissions in the process of sintering iron.
The Chinese iron industry is oriented on modification of uneconomical structure of the iron production, excessive energy consumption and heavy impact on global environment.
Research limitations/implications: Simulation calculations show that the future lines of the development of blast furnace technology should take into account: a) use lower temperatures of hot blast and high blast enrichment in oxygen. b). injection of various fuels taking into account their prices in various world regions, c). the effective use of top gas, d). the possibility of eliminating blast furnace stoves.
Originality/value: of the paper consist in transfer of knowledge helpful to further lowering energy for iron production and reducing harmful impact for the natural environment.
Keywords: Iron manufacturing; Worldwide production; Blast furnace; Technology; Modernization; Future prospects

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1. Introduction

A huge increase in steel production in the world in recent years (Fig. 1) requires a sufficiently large production of iron [1].

A leading technology in the manufacture of iron is still blast furnace technology, which provides approximately 94 wt% iron in the form of pig iron.

The projected in the 1980s development processes the reduction of smelting reduction, based on the use of non-coking coals, which was gradually to replace blast furnace process, has not checked so far. The reasons for this is the fact that:

- firstly: resources of coking coals prove continue to be large enough to ensure the appropriate quantity of coke for the process of blast furnace in the near future,

- secondly: new technologies smelting reduction will be rather in evolutionary i.e. gradually, and not in revolutionary way replace the blast furnace technology. The reasons for this are manifold: (1) in terms of volume of production (taking into account one aggregate) new technologies are not able to replace the blast furnace, (2) a vast capital of these investments and a long technical life of blast furnaces, (3) the smelting reduction processes since the 1980s are still in the development stage.

The third way of the iron production are direct reduction of iron (DRI) technologies. The product of these technologies, i.e. sponge iron is the most commonly used in electric arc furnaces (in mini-steelworks), with the aim of lowering the level of irremovable admixtures in the steel produced from iron scrap. Also in these technologies solutions are looking for to ensure the competitiveness of the product, by lowering quantity of energy used per unit of pig iron and improving its quality.

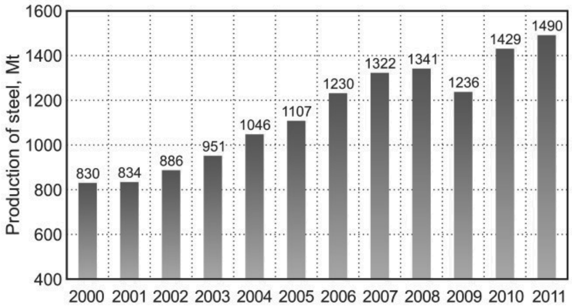

Fig. 1. Worldwide production of crude steel within 2000-2011 years [1]

2. Current modernization and directions of development of blast furnace technology

From the beginning of the current century there was a radical increase in production of pig iron in the world (Fig. 2). From the data provided it is seen that within the period 2000-2010 production increased by 80% and in 2011 recorded significant further growth. A decisive part in this growth have China in which production of pig iron increased during this period from 130 to 630 million tones.

A characteristic feature of the development of blast furnace technologies in the last 10 years is the increase the overall productivity of blast furnaces, which is an average of 2.1 $t/m^3/24$ h and the increase in volume blast furnaces and extending the period for campaign work of blast furnaces to more than 20 years [2].

Taking into account the longer period of development blast furnace process (approx. 40 years), it is concluded that the modernizations had been expressed in the systematic improving the quality of blast furnace charge, controlling the charge distribution, the introduction of coal dust injection and modernization of the equipments, among others the cooling system of the blast furnace and the introduction of multi taphole technology operation [3].

In addition, depending on the region of the world, there are various other lines of the improvement of blast furnace process, which are presented in this paper.

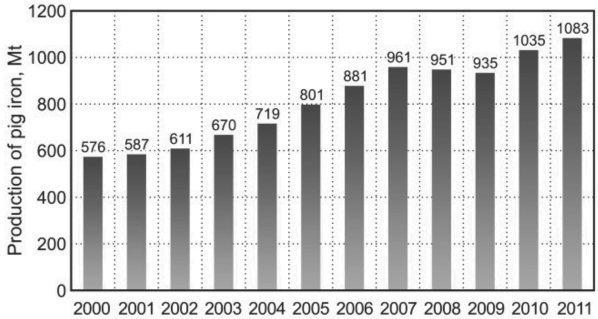

Fig. 2. Global production of pig iron in years 2000-2011 [1]

2.1. Japan

In the case of Japan, technology development and production of pig iron focuses, among others, in the following areas:

- preliminary preparation of ores to sintering (new process granulation for the control of melting materials) [4],
- the extension of the campaign of blast furnaces, primarily in the area: carbon lining - liquid iron by creating adhesive layers of high corrosion resistance [5],
- decreasing CO_2 emissions in the process of sintering iron ore by applying injection of natural gas from the top downwards sintered layer [6],
- hybrid bonding iron ore of inferior quality [7],
- natural gas injection to the blast furnaces.

2.2. USA, Canada and Mexico

In the case of the United States, Canada and Mexico important direction of activity is extending the campaign blast furnaces and their selective upgrading and modernization [8,9], among others through refractory gunning. This technology is currently dominant; from the year 2000 to this moment in this way were re-profiled 25 of 36 blast furnaces North America. The only negative feature of this mode of refractory renovation is the need to stop the work of the blast furnace more or less every two years, which may in turn have serious implications, as regards the durability of the hearth of the blast furnace. However, as so far the design of the blast furnace hearth and work technology of the blast furnaces in North America are adapted to the requirements related to this way renovation of blast furnace refractory [10].

The increase in price of coke was a cause of the expectations that there will be a substantial acceleration in the implementation of the installation for injection of coal to blast furnaces. However, it has appeared that dominant philosophy to reduce consumption of coke is, for the majority of companies, policy of „co-injection”, which means the use of several alternative fuels i.e. gas, liquid fuels, coal dust and tar.

The main component of the iron-bearing charge for blast furnaces in the region are still pellets (approx. 90%), in most basic pellets, while the use of acidic pellets also takes place in the case of disposal of sinter of higher basicity. An important feature is the use, in many cases, return materials in sintering mix.

2.3. Western Europe (EU 15)

Production of pig iron in the countries of Western Europe (including the 15 countries of the former EU) in 1990 was around 94 million tones and was achieved in 92 blast furnaces. In 2008 there worked only 58 blast furnaces units producing 90 million tones of pig iron. Calculations have demonstrated that, with an average increasing the average volume of blast furnaces (in the periods being compared) by 26.6% from 1630 m^3 to 2063 m^3, the average annual production (at one blast furnace) increased by 48% from 1.04 to 1.54 million tones. This means that increasing the size of blast furnaces were accompanied by undertaking significant efforts to intensify the work of blast furnaces [11].
Consumption of coke decreased from 408 kg/t of pig iron (1990 year) to 352 kg/t of pig iron in the year 2008, as a result of increased quantities of injected gas from 50 to 124 kg/t of pig iron. The consumption of liquid fuels and other fuels substitute decreased slightly from 23 to 20.3 kg/t of liquid pig iron.
The largest amount of injected coal dust was noted at blast furnace no. 6 in Ijmuiden and it was 235.1 kg/t of pig iron, at consumption of coke in quantities 289.9 kg/t liquid metal. The smallest general fuel consumption, at the level of 458.5 kg/t of pig iron, has been achieved in Ruukki metallurgical works at blast furnace no. 1.

The structure of iron-bearing materials that are charged to blast furnaces is very differed and may consist of: both almost the sinter itself (approx. 90% - ArcelorMittal), and with the pellets itself (SSAB). In 2008 the increasing of the share of crude iron ore can be seen, in some cases even to 30%.

2.4. China

In China the average growth of the production of pig iron in the last decade of the 20th century was 6.87 Mt/year, while in the years 2000-2008 increased sharply to 46.8 Mt/year. This is connected with the increase in the number of blast furnaces with 196 to 475, and with simultaneous increasing their average volume, as shown in Fig. 3 [12].

In Fig. 4 the change of quantity of consumed main raw materials for the production of pig iron in the years 2000-2008 is shown. The data suggest that index pellets/sinter increases in this period from 8.1 to 19.0%. An unit coke consumption decreased in years 2001-2008 from 426 to 396 kg/t of pig iron, while consumption of coal dust increased from 120 to 136 kg/t liquid metal. Total fuel consumption decreased in this period from 546 to 532 kg/t of pig iron.

Percentage content of the iron in blast furnace charge is very stable and has fluctuated during the period 2000-2008 between 57.16-58.49 wt%. An average blast furnace temperature has been fluctuating in the range of 1066-1133°C.

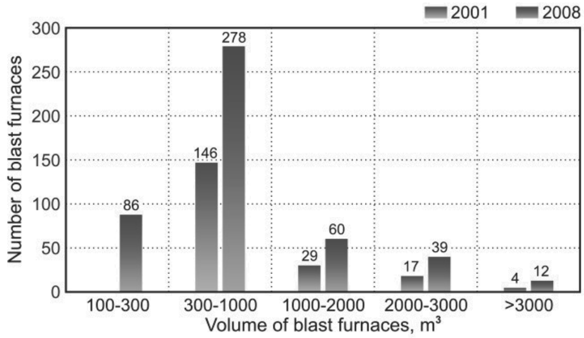

Fig. 3. The volume and number of blast furnaces in China in 2001 and 2008 years [12]

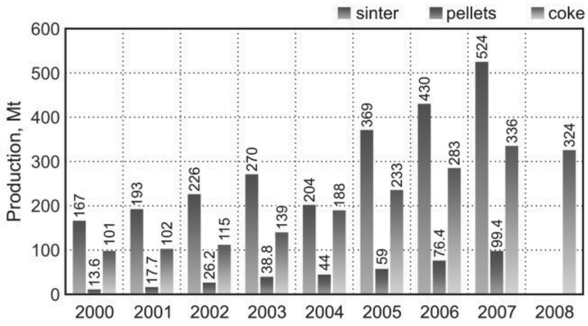

Fig. 4. Production of sinter, pellets and coke in the period 2000-2008 years in China iron and steel industry [12]

A major progress has been noted in that time in the field of environmental protection; SO_2 emissions decreased from 6.09 kg/t steel in 2000 to 1.55 kg/t steel in the year 2008 [12].

3. The predicted directions of further changes in blast furnace technology

Considerations, as to further changes in blast furnace technology include the following problems [3]:

- injection of coal dust vs injection of fuel oil as alternative fuels,
- use lower temperatures of hot blast and high blast enrichment in oxygen (the possibility of eliminating blast furnace stoves),
- the effective use of top gas,
- the work of the blast furnace with eliminating nitrogen in gas, i.e. possibility of operation at 100% oxygen in blast.

These ideas are based on 2-stage model mass and heat balance, which allows, among others, to use different types of alternative fuels. The model concerned the blast furnace of day output 10000 t, at consumption of coke 300-325 kg/t of pig iron and approximately 170-200 kg coal injected per 1 t of pig iron [3].

Ad a). considerations concerning the coal or gas injection are associated with broad prices diversification of these raw materials. As can be seen from Fig. 5, the price of 1 GJ obtained from coal (PCI benchmark) and gas in the US has got closer to each other and are almost identical.

Consequently, the economics of coal or oil injection will be dependent on regional prices of these raw materials. The simulation calculations was carried out for 3 variants of the application of alternative fuels: coal, fuel oil and natural gas. In Table 1 the basic data used in the calculations are presented.
Fig. 6 presents the results of the calculations in respect of cases of coal dust and natural gas injection as alternative fuels.

These results in the form of indicators - so-called Operational Expenditures (OPEX) - shows advantage for PCI injection compared to gas injection in two countries i.e. Germany and USA. In conclusions, the authors [3] claim that injection of coal will remain a matter of choice in most regions of the world.
And so: applying the German price from I quarter of 2011, it can be seen from Fig. 6 that coal injection to blast furnaces in Germany gives an advantage amounting to 35 USD in relation to the variant of natural gas injection.

In the period 2005-2011 benefits from injection of coal in the USA (compared to injection of natural gas) decreased largely to around 10 USD/t of pig iron, which is due to the decrease in prices of natural gas (Fig. 5). It is estimated that use of natural gas instead of coal dust allows reduce CO_2 emissions approximately by 50 kg/t of pig iron.

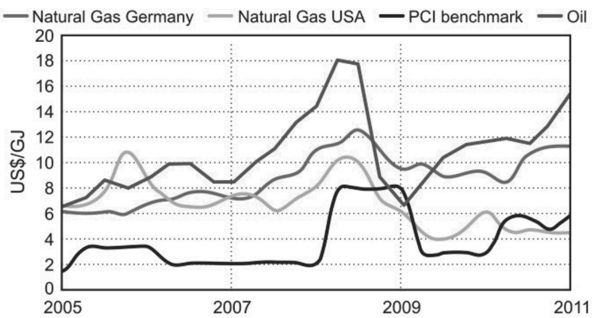

Fig. 5. Price development of 1 GJ of oil, natural gas and injection coal in period 2005-2011 (USD/GJ)

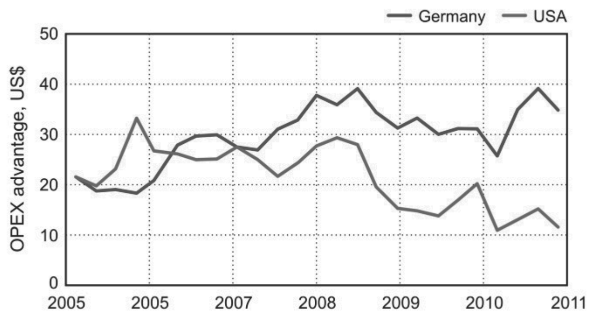

Fig. 6. OPEX advantage for coal injection compared to gas injection in two countries

The possibilities of saving coke in the case of coal injection are much larger in comparison with injection of natural gas due to the impact on the temperature of the flame in the combustion chamber and a temperature top gas. In the case of natural gas injection, removal of restrictions linked to the getting of the dew point temperature in top gas requires much greater consumption of coke compared to the case of coal injection.

Ad b). In most of integrated ironworks the enrichment of hot blast in oxygen attain level of 26-29 vol%. In some cases, the enrichment reaches even the level of 35 vol%, first of all in the mills using natural gas (e.g. Ternium Siderar and AK Middletown mills, but also Corus Ijmujden which uses coal as substitute fuel). In connection with that, the authors of work [3] carried out a simulation calculations to find out in which conditions the decreasing of hot blast temperature and increasing of oxygen share in hot blast are economically reasonable. The results of simulation refer to changes of quantities of coal injected and the changes of oxygen share in hot blast per 1 t of pig iron (Fig. 7) and OPEX effect (Fig. 8).

Calculations are performed assuming a constant quantity of coke in the charge equal to 300 kg t of pig iron and a stable temperature flame in the combustion chamber around 2000°C.

As can be seen from Fig. 7 decreasing of hot blast temperature from 1150 to 150°C will require compensation in the form of increasing quantities of coal from 196 to 286 kg/t of pig iron and increase the quantities of oxygen in the blast from 61 to 256 Nm^3/t of pig iron.

Table 1.
Data for variant simulation calculations of injection of coal (I), fuel oil (II) and natural gas (III) [3]

Factors	Units	Variant			Elemental analysis				
		Coal(I)	Fuel Oil (II)	Natural gas (III)	Elements/others	Units	Coal	Fuel Oil	Natural Gas
Coke rate (87.5%C)	kg/t	324	379	408	C	wt%	81.7	86.6	64.0
Coal	kg/t	170	0	0	H	wt%	5.1	11.0	21.2
Oil	kg/t	0	90	0	O	wt%	5.2		0.6
Natural Gas	kg/t	0	0	80	N	wt%	1.3		14
Oxygen	Nm^3/t	92	60	85	S	wt%	1	1	0
BH gas export	MJ/t	3695	3384	3976	Ash	wt%	6		0
BF gas calorific value	MJ/Nm^3	3920	3609	3966	Total	wt%	100	98.6	99.7
					Cracking heat	GJ/t	0.5	1.1	4.0

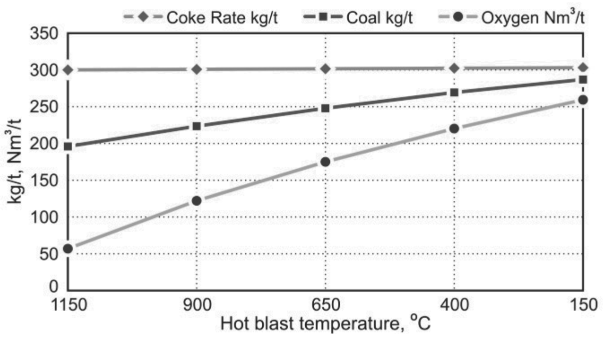

Fig. 7. Effect of decreasing hot blast temperature on coal rate at constant coke consumption 300 kg/t of pig iron

According to data of Fig. 8 it is concluded that decreasing the hot blast temperature within the specified range of, when using compensation in the form of increased quantities of coal and oxygen in the blast (as it is shown in Fig. 7), gives the different effects when it comes to operational expenditure index OPEX. An increase in this index (together with a reduction in the temperature of hot blast)) is taking place when the top gas is used at a price of coal injected. But in the case of the use of top gas for electricity production, value of operational expenditure shall be reduced, and in case of electricity price 0.06 USD kWh the difference is equal to 5.7 of the USD t of pig iron, but with the price 0.09 USD kWh - the difference amounts to 22.7 USD/t of pig iron.

The calculations of the simulation showed also, that decreasing the temperature of hot blast also offers benefits in relation to the efficiency of the blast furnace. The reduction of the temperature of hot blast affect in a small way to CO_2 emissions and on the ratio of coal/oxygen in the tuyers in the blast furnace.

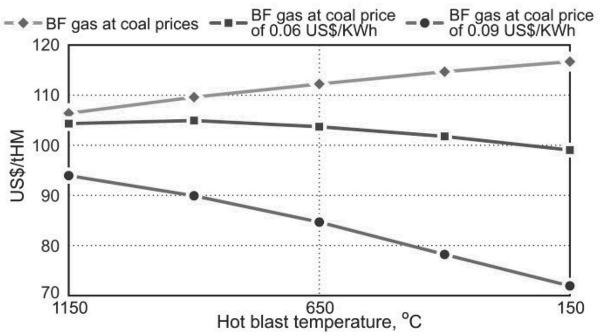

Fig. 8. Effect of decreasing hot blast temperature on the operational expenditures for coke, coal, oxygen and top gas benefits, which were taken as equivalent coal and power prices (0.06 and 0.09 USD/kWh)

Modern structures of blast furnace stoves make possible to achieve the hot blast temperature 1300°C and more. At blast temperature of 900°C constructions of blast furnace stoves may be much simpler and cheaper, and at a temperature of blast 600°C continuous heat exchangers may be applied, which will eliminate approximately 2% of the losses hot blast and oxygen from stove depressurization as well as a major cause of pressure swings in the blast furnace. Theoretically, it is possible to eliminate the blast furnace stoves and to apply „cold" blast of temperature range 100-250°C. The necessary concentration of oxygen in blast will reaches then 51 vol%. In this case, both the flame of temperature, and the ratio C/O in raceway should be within the normal range.

An increased consumption of oxygen, causes in consequence increase in the productivity of the blast furnace without additional heat loss, which provides an advantage of about 12 kg coal per 1 ton of additional hot metal [3].

Ad c). In the situation a significant decrease of hot blast temperature or elimination of the hot blast furnace in general, blast furnace becomes effective gas generator equipped with cooling system, dust gas desulphurization and dust removal system. This gas may be used in electricity production in a much greater extent than in the event of its use for heating up of blast furnace stoves. Calculations show that, in case of application of cold blast (150°C) the blast furnace (BF) gas (export after stoves) will have the energy value 7408 MJ/t of pig iron, while in situation of application of hot blast with a temperature of 1150°C, calorific value of gas will be twice less and will be 3593 MJ/t of hot metal.

Ad d). Authors of the work [3] analysed the possibility to work with the elimination of nitrogen in gas i.e. in the 100% oxygen in the blast. It was conclude, that the use of the cold blast at 100% oxygen in it, causes increase the temperature of the flame in the combustion chamber to around 2800°C and results in a shortage of the quantity of gas in the upper part of the blast furnace. According to the fundamental assumptions simulation calculations the quantity of coke was 250 kg/t of pig iron and the quantity of coal injected 367 kg/t of pig iron. In order to decrease the flame temperature in the combustion chamber, the injection of 10 wt% of ferrous fines through the tuyers had been in calculations assumed.

A shortage of gas could be compensated by injection of hot gas in the upper part of the blast furnace (ULCOS project), although the best solution is the generation of appropriate quantities of gas in the tuyers and raceway region.

4. Summary

The production of iron in the world is still dominated by blast furnace technolog, whose participation in 2011 was 94.1% [3], with the global production of 1083 million tonnes of pig iron. Directions of modernizing blast furnace process depend in large part on the region of the world.

A characteristic feature of the development of blast furnace technologies in the last 10 years is the increase the overall productivity of blast furnaces, which is an average of 2.1 t/m^3/24h and the increase in volume blast furnaces and extending the period for campaign work of blast furnaces to more than 20 years.

Within the longer period of development blast furnace process (approx. 40 years), it is noted that the modernizations consisted in the systematic improving the quality of blast furnace charge, controlling the distribution charge, the introduction of coal dust injection and modernization of the equipments, among others the cooling system of the blast furnace and the introduction of multi taphole technology in blast furnace operation [3]. Despite of that, some specific researches were carried out, for instance new process granulation for the control of melting materials, hybrid bonding iron ore of inferior quality, decreasing CO_2 emissions in the process of sintering iron ore by applying injection of natural gas from the top downwards sintered layer.

The current situation in the steel industry in the world is largely determined by a sharp increase in production potential of the Chinese iron and steel industry.

Authors of the plenary session in Congress ICSTI'09 in Shanghai underline that the most important challenges in the further development is the modification of uneconomical structure of the iron production, excessive energy consumption and heavy impact on global environment.

In addition, the Chinese steel industry should be oriented towards the domestic market. Assuming that even for a long period of time, China will be completing its „iron fund" and to lessen the index: iron production/steel production, one should not afraid of too much expansion to external markets.

Simulation calculations show that the future lines of the development of blast furnace technology should take into account: a) use lower temperatures of hot blast and high blast enrichment in oxygen, b). the possibility of eliminating blast furnace stoves, c) the effective use of top gas, d). injection of various fuels taking into account their prices in various world regions.

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