System reliability of blast furnace process using pulverized coal injection

Bolshakov V.I., Chayka A.L., Lebed V.V., Sokhatskiy A.A., Tsyupa K.S., Kornilov B.V.

Iron and Steel Institute of the National Academy of Sciences of Ukraine

Abstract

The paper shows that the successful development of blast furnace smelting practice with using pulverized coal injections at the metallurgical enterprises of Ukraine requires a comprehensive review and resolution that covers not only improvement of charge conditions for the blast furnace and technical re-equipment of furnaces, but also the development of rational management practices of blast furnaces thermal performance based on control of the burden distribution, harmonization of thermal and gas-dynamic work of the furnace top and bottom, the choice of parameters and the composition of the blast, organization of the tuyere zone effective work in the existing conditions of charge, taking into account the technical condition of the furnace, the requirements for performance and quality of pig iron. Resolution of these issues is especially important for Ukrainian BF of high-volume –2000÷5000 m^3.

Keywords: BLAST FURNACE, PERFORMANCE, POWER CONSUMPTION, PULVERIZED COAL, BELL-LESS TOP, OPTIMIZATION, HEAT AND MASS EXCHANGE, GAS DYNAMICS, TURBO-BLOWERS, STOVE, HEARTH, TUYERE ZONE, SHAFT, TOP

The first industrial experiments on the pulverized coal injection (PCI) and natural gas in the blast furnace were carried out at the metallurgical enterprises of Ukraine in 40-60 years of the last century, and later in the USA and Western Europe [1 - 3]. Type of fuel additives used in blast furnaces was determined by its availability and cost. By 1960, with the participation of Iron and Steel Institute (ISI) the technology of works using natural gas at more than 30 blast furnaces of Ukraine was mastered [4].

Currently due to the high prices of natural gas and its deficit, the plants of Ukraine transfer from the technology of working with natural gas to blast furnace smelting technology with PCI: PJSC "Alchevsk Iron and Steel Works" ("AISW") - 2009, "Zaporizhstal" - 2011, " Ilyich Iron and Steel Works "- 2012," Dneprovsky Iron and Steel Works "- 2014. ISI NAS takes an active part in the development of modern technology of blast furnaces with PCI at PJSC "AISW", PJSC " Ilyich ISW" and JSC" Zaporizhstal "in the framework of R & D with plants [5 - 8].

The world's first industrial test of technology of PCI into the blast furnace was implemented in Ukraine at the plant after Dzerzhinsky in 1948 [1, 2]. In 1966, at "Zaporizhstal" on the initiative of Z. I. Nekrasov the first domestic unit of PCI in the hearth of blast furnace No 3 with capacity of 1300 m^3 was built and developed by the technological task of the ISI and on the project of Ukrgipromez [1, 9]. In 1980, the construction of industrial PCI unit into blast fur-

naces No 1, 2 was completed on the Donetsk metallurgical plant and, later the smelting technology with PCI was mastered successfully at the "DMP" [1, 10].

The researches of the Iron and Steel Institute after Z. I. Nekrasov, I.P. Bardin Central Research Institute for Ferrous Metallurgy, Dneprodzerzhinsk Industrial Institute, Donetsk Iron and Steel Institute, Karaganda, West Siberian, Dnieprovsky after Dzerzhinsky metallurgical plants, "Zaporizhstal" and Tula metallurgical plants are dedicated to issues of development the blast furnace smelting technology using PCI and equipment for its implementation .

The consulting assistance on the PCI into the furnace of the Dzerzhinskiy metallurgical plant was made by a founder of the furnaces energy theory – I. D. Semikin, who had the long-term relationships in resolving the various problems of metallurgical heat engineering at the plant in the field of steel metallurgy, rolling production and experience in the use of PCI for heating the largest reverberatory furnaces in nonferrous metallurgy. Later, I. D. Semikin proposed method for calculating the optimal balance between oxygen, blast temperature, different fuel and other additives: natural gas, coal dust, steam, using the concept of fuel utilization factor (FUF) and the method of thermal compensation [11]. This method played an important role in mastering the technology and development of technique of the fuel-enriched blast application in blast furnaces, as noted by several investigators [12-14], and laid the foundation for the selection of optimal parameters of blast furnaces mode by formalized methods of mathematical programming [14].

Obtained by a single method (calorimetric method) and systematized experimental data have shown that the thermal processes in the peripheral zone are an important factor of stabilization and efficiency of the smelting technology, reliability and durability of blast furnaces. They have been used during the development of blast furnace smelting technology with fuel-enriched blast of high parameters in the furnaces with the large unit capacity (capacity 3000 - 5500 m^3), when improving constructions and modes of operation of the furnace cooling systems, the development of mathematical models of the blast furnace process and also they entered the educational and reference literature and initiated the development of a new scientific direction in metallurgy - blast furnace system reliability [14, 15].

The development of integrated experimental-industrial and scientific-research works usually requires the combined efforts of specialists in various directions. Z. I. Nekrasov widely used principle of scientific cooperation, attracted and united efforts of many well-known experts for the focused implementation of such works. He actively collaborated with V. I. Karmazin on the issuers of obtaining and melting rich "superagglomerate", with I. D. Semikin, B. I. Kitaev on thermo-technical problems in metallurgy, with V. S. Kudryavtsev for obtaining metallized raw materials, and with a number of design institutes.

Generally, the technologist considers its problem too narrowly, taking into account only a single segment of a complex energy-technological cycle what the production of metal is. This can adversely affect the operational reliability of units, metal quality and gives a decisive role to flexibility, i. e. rapid and economic rearrangement of technological regimes of the units and industrial complex in general. In this direction, to the analysis of technological modes it is advisable to add the use of the work patterns of the furnaces thermal performances and energy balance of blast furnace smelting.

Currently, heat and power approach to the study and improvement of the operating modes of the blast furnace has been successfully used in basic and applied researches[1] conducted by ISI of NASU on the development of a new scientific direction in the field of blast furnace - system reliability in production of pig iron [14, 15].

The system reliability refers to the ability of production and the enterprise in general to keep required production level of metal of specified quality at regulated effects on the environment and power consumption during the operation within a certain range. The main objective of this direction for the blast furnace is to find by formalized methods and on the basis of experimental smeltings the compromise solutions providing: 1) the required amount of smelting the pig iron of specified quality; 2) the minimum consumption of energy resources; 3) the technical reliability insurance of the blast furnace and its service units and minimum harmful effects on the environment (Fig. 1). System reliability is characterized by the tight interweaving of the theory and best practices achievements and cooperation of focused efforts of various specialists.

During the past five years with the use of scientific approaches mentioned above the works were carried out on the development of blast furnace technology

[1]The work involved: A.V. Borodulin, A. A. Zherebetskyi, V. G. Zaitsev, N. N. Lychagin, A. A. Moskalina, I. A. Ostashko, G. V. Panchoha, K. S. Tsyupa, A. G. Shevelev, V. Y. Shostak.

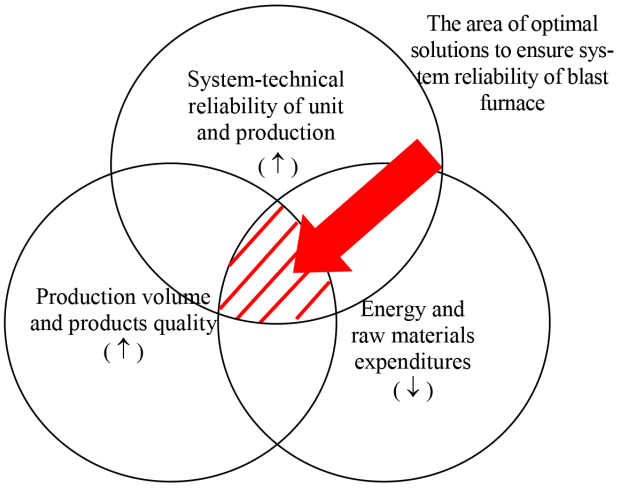


Figure 1. The architecture of the system reliability of the blast furnace and adoption of compromise solutions on its maintenance

with PCI in the blast furnaces of PJSC "AISW" and PJSC "Ilyich ISW", technology of furnace blowing-in without natural gas on the PJSC "ArcelorMittal Krivoy Rog ("AMKR") and on PJSC "Ilyich ISW", mastering of forced and energy-saving blast furnace technology at put into operation in 2011 BF No7 of JSC "Novolipetsk Iron and Steel Works" ("NISW") with useful volume of 4290 m^3, the introduction of automated control systems of external thermal loss of blast furnaces PJSC "AMKR" and PJSC "Zaporizhstal". The names of some of these works and the results obtained are listed below.

In the work "Pre-start researches of the loading system equipment operation. Improving the distribution of the raw materials on the top, the development of measures and technological solutions to increase the efficiency of the blast furnace No1 of PJSC"AISW" "(Head - V. Bolshakov 2010) the principles were grounded, the technology of the joint supply of natural gas and pulverized coal to all tuyeres, including the establishment of rational ratios of fuel additives to the blast, process oxygen and oxygen supplied with the pulverized coal through the burner units at the maximum attainable blast temperature with taking into account the chemical composition of pulverized coal was implemented and mastered together with technologists of PJSC "AISW" [5 - 7].

Rational management of the distribution of the raw materials on the top by the fuel combustion mode in the tuyere zone and the output of melting products allowed during 2011 to achieve at BF No1 PJSC "AISW" the best techno-economic indicators in Ukraine, which correspond to world practice of the BF work with PCI (Fig.2). Coke consumption was about 395- 400 kg /t of pig iron, which was on 70-100 kg/t pig iron less than when working without PCI. Natural gas consumption was 33m^3/t of pig iron. In comparison, before the use of pulverized coal, 85 – 90 m^3 of natural gas per ton of pig iron was used. PCI consumption was 130 kg /t of pig iron when production of pig iron was about 6300 tons per day in the blast furnace with volume of 3000 m^3 [5 - 7].

It is found that when blowing the natural gas, in comparison with the injection of pulverized coal, gas-dynamic mode is more stable, due to lower content of FeO in the primary slag. When blowing PCI gas-dynamic resistance of blast furnace increases depending on the chemical composition of the fuel due to the enlarging of the iron oxide content and the amount of primary slag [16, 17].

As a consequence, the oscillatory processes in gas – dynamic system of "turbo blower - blast furnace" increase. In case of disturbance, such as the collapse of the charge in the blast zone oscillations with large amplitude appear. This negatively affects the stability of furnace operation and service life of the turbocharger. A compromise variant is a joint injection into the hearth of the blast furnace of pulverized coal and natural gas (Fig. 3).

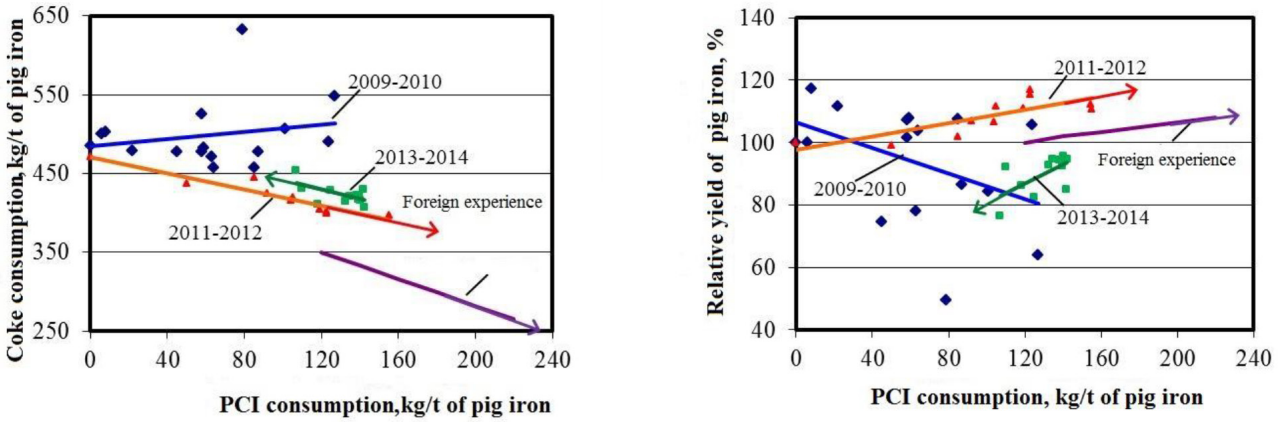


Figure 2. BF No1 performance indicators at PJSC "AISW" in 2009-2014

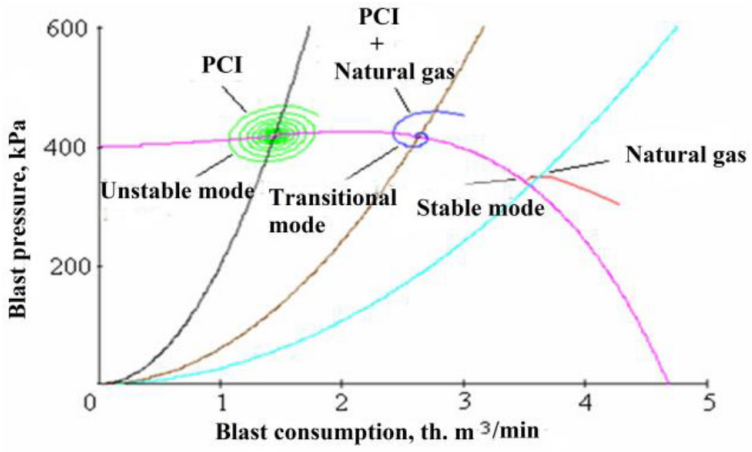


Figure 3. Phase portraits of turbo blower- blast furnace system when application of natural gas, pulverized coal and mixture thereof

In the unstable conditions of the furnace operation and at the low quality of raw materials joint injection into the furnace hearth of small amount of natural gas, that is about 30 m^3/t of pig iron, together with PCI, through all blast tuyeres reduces the thermal loads on the hearth and the bottom of the furnace shaft, conduces more stable gas-dynamic system "turbo blower-blast furnace" operation and reduces the circumferential unevenness of furnace thermal performance.

In 2013, cooperation with PJSC "AISW" was continued in the framework of the research project "Investigation of the parameters of distribution of the raw materials and charging system equipment performance, the development of rational modes of BF No1 of PJSC" AISW "with the use of pulverized coal" (Head – V. I. Bolshakov, 2013). On the basis of pre-start researches carried out in the framework of R & D, rational parameters of the charging system equipment performance of BF No1 PJSC "AISW" were recommended. The rational modes of the furnace operation were developed, providing the average daily production of pig iron up to 5500 t/day with pulverized coal injection of 150 kg /t of pig iron and more without the use of natural gas, taking into account considered unsatisfactory, emergency technical condition of the furnace shaft [5 - 7].

The method of instrumental measurement of profile distortion of the blown out furnace with the use of laser devices was proposed and successfully tested.

The regularities of the influence of work technology with PCI on the thermal losses in the cooling system, the circumferential and vertical unevenness of refrigerators burning and failure of the tuyeres were established. The technical measures to increase the service life of the blast furnace shaft transferring on the blast furnace technology with PCI were substantiated and proposed.

The amendments draft to the technological instructions for conducting the blast furnace with PCI was prepared. The recommendations for forcing, increasing the efficiency and extension the service life of the BF No1 at PJSC "AISW" ware developed.

Experience of the mastering PCI in the period of 2009-2014 on the second largest blast furnace in Ukraine BF No1 at PJSC "AISW" with useful volume of 3000 m^3 has shown that a greater volume of the furnace allows to increase the effect of the transition to work with the PCI technology in comparison with furnaces of small volume, but at the same time, it increases the demands on the technical equipment of the furnace, its cooling system design and the quality of raw materials [5 - 7, 18]. In June of 2014 BF No1 was stopped for extended overhaul repairs of the second category, which provided the implementation of new technical solutions in the design of the furnace, the loading equipment and the cooling system.

Analytical and experimental studies of coolers functional loss dynamics of BF No1 at PJSC "AISW", changes of the thermal loads on height and perimeter of the furnace and the thermal losses in the cooling system have shown that the main reasons for reducing the service life of bosh, blast-furnace lintel plate and the shaft bottom of BF No1 are changes in thermal and gas-dynamic work during the transition to the blast furnace smelting technology with injection of pulverized coal [5 - 7]:

- an increase of thermal loads on the furnace cooling system, especially in tuyere belt, hearth, bosh and shaft bottom;
- a deterioration of the furnace run evenness due to the increase of ore load on the coke by 25% and decrease the gas permeability of the charge column, peculiarities PCI burning in combustion zone;

• an increase of production and a degree of direct iron reduction, the amount of primary slag and content of iron monoxide in it;

• an increase of the circumferential irregularity in thermal and gas-dynamic furnace operation.

The consequences of the influence of the BF No1 transition to blast furnace smelting technology with PCI on coolers combustion is shown in Fig. 4.

The number of out-of-operation elements of water-cooled furnace elements was increased with rising the value of circumferential unevenness and value of temperature and thermal loads in bottom of the furnace, especially on the bosh and tuyere connections with increasing PCI consumption. The thermal load on one tuyere rose from 130 ÷ 190 to 160 ÷ 240 kW, the unevenness of their distribution increased by more than one and a half times. The average value of the external thermal losses of studied furnaces working space according to instrumental measurements when working with natural gas amounted to 14 MW, when using PCI and natural gas - 20, only with PCI - 23 MW [5 - 7].

In the work "Development and technological support of the rational measures providing the blast furnaces of PJSC "Ilyich ISW" efficiency increase by using pulverized coal" (Head - V. I. Bolshakov, 2014) on the basis of experimental and analytical studies of gas-dynamic and thermal mode of the blast furnaces the reasons for premature failure of the tuyere connections under conditions of PCI application were determined. The recommendations to adjust the slag, thermal and gas dynamic melting regimes and parameters of the furnaces loading mode with raw materials were developed and proposed. During the period of implementation of R & D number of replaced tuyeres was decreased by 63%, and burnt on the top - by 72%.

In the work "The study of dynamics of the lining deterioration and thermal work of the shaft cooling system of BF No4 JSC "Zaporizhstal", the development of recommendations for the prevention of coolers failure in working conditions with the use PCI" (Head – A. L. Chayka, 2015) the regularities of influence of blast furnace smelting technology with PCI on the lining deterioration, kish formation and thermal loads on the shaft height were determined (Fig. 5).

The measures aimed at reducing the thermal loads on the shaft and bosh by choosing rational gas-dynamic loading mode were proposed and implemented. The influence of the charge and PCI composition on the lining wear and the processes of kish formation were determined. For the first time the quantitative relationship between lining wear, thermal losses in the cooling system and consumption of coke on their covering were defined (Fig. 6). The rational decisions on construction and modernization of technical equipment of blast furnaces working with PCI were substantiated.

In the work "Development of methods and mastering of measures for the use of the information on the thermal losses in the cooling system, lining and shell temperatures of BF No9 PJSC "AISW " for detecting at an early stage and taking measures to prevent" disturbances "in the furnace operation" (Head - A .L. Chayka, 2011) the subsystem "Control of external thermal losses and consumption of coke on their covering" was developed and implemented as part of automatic process control system of BF No9. The

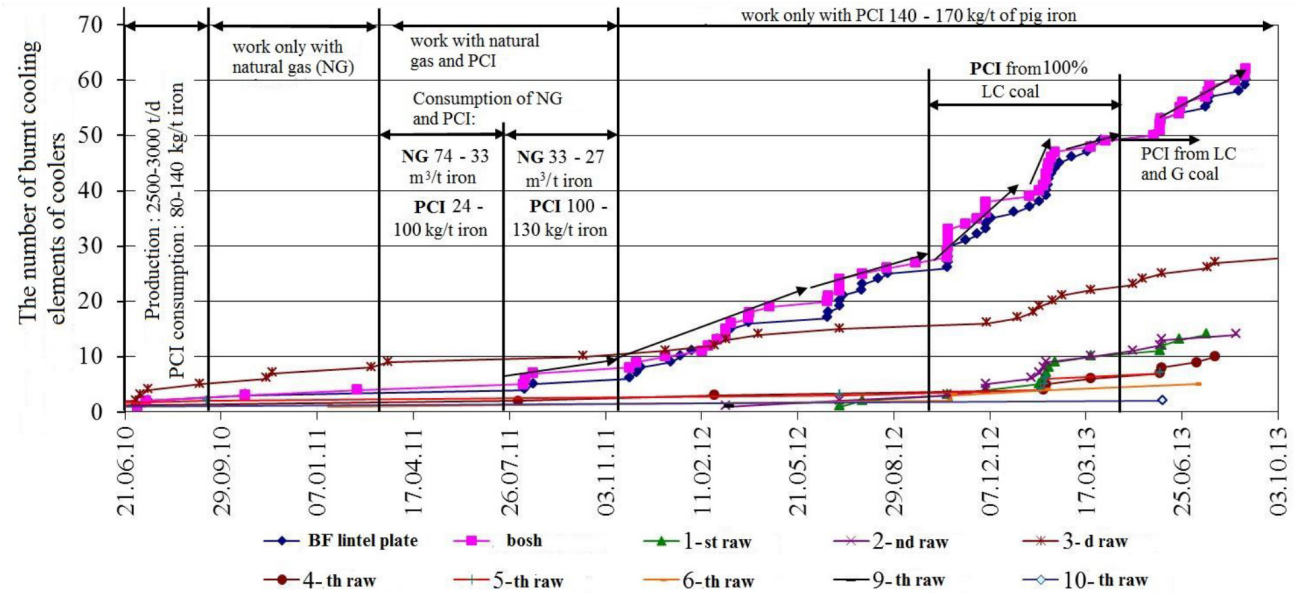
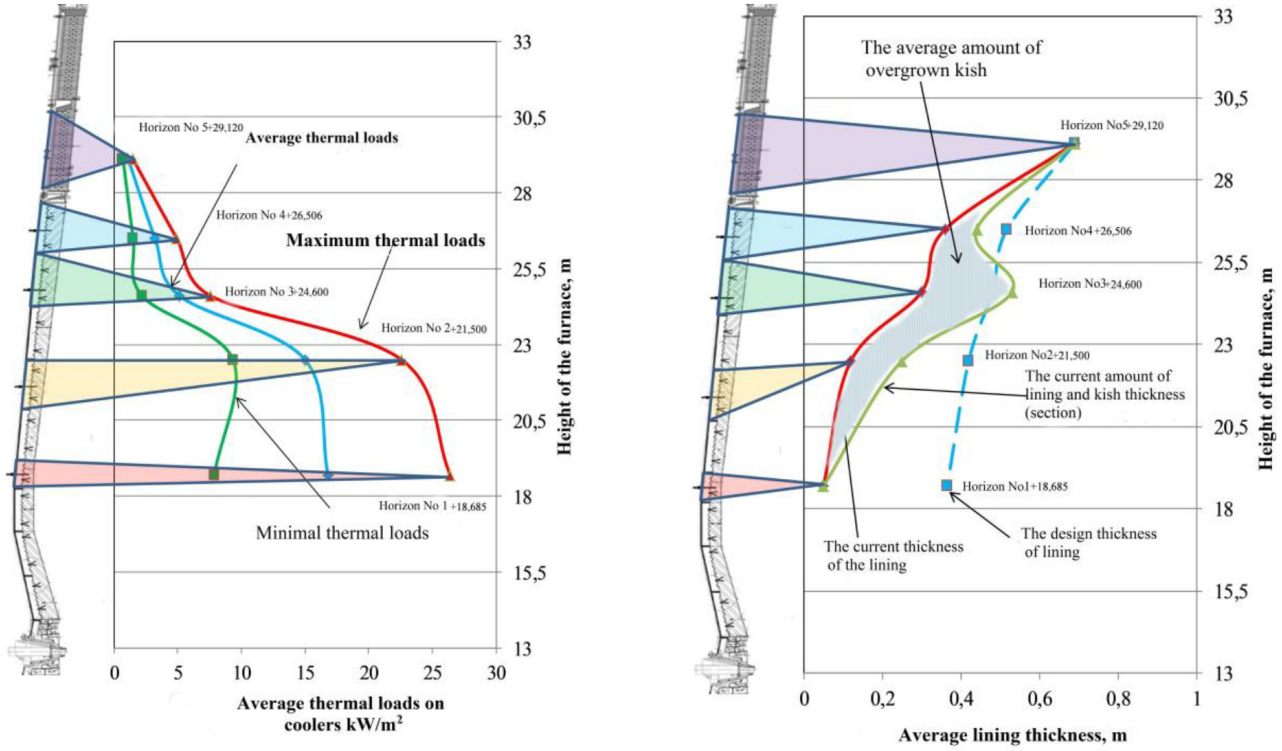


Figure 4. Combustion dynamics of water-cooled tubes of coolers of bosh, blast-furnace lintel plate and shaft of BF No1



a b

Figure 5. The minimal, average and maximum thermal load on the cooling plates (a), the current lining deterioration and kish from the beginning of the campaign to March 2015 (b)

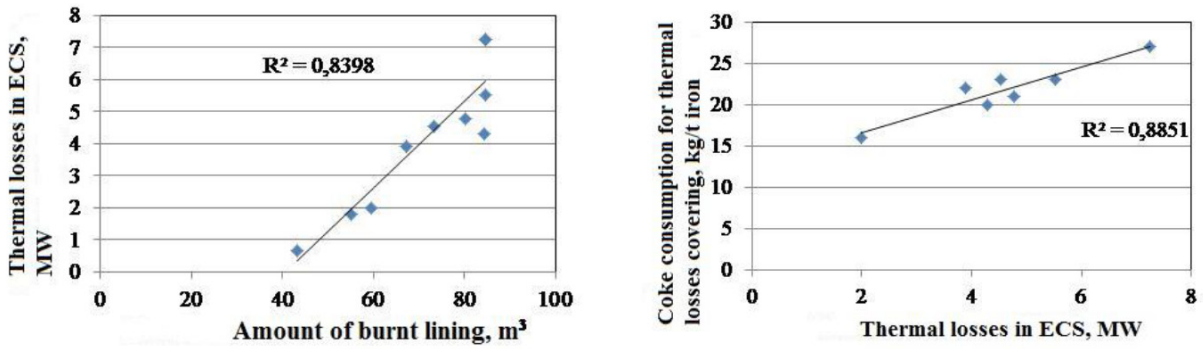


Figure 6. Impact of the lining deterioration on the vapor outlet from the evaporative cooling system (ECS) and on the value of the external thermal losses and coke consumption on their covering BF No4 JSC "Zaporizhstal"

recommendations and directions of using information from the subsystem for preventing "disturbances" and increasing operational reliability of the BF No9, reducing the coke consumption, evaluating the effectiveness of the selected heat-gas-dynamic mode when changing the parameters and blast composition, pressure in the top area and furnace loading program were developed (fig. 7) [16, 19].

In the work "Technological support of preparatory measures and blowing-out of BF No9. Technological support of blowing-in BF No9 PJSC "AISW" (Head - V. I. Bolshakov, 2008) the recommendations on the organization of rational heat-gas-dynamic mode of blowing-out and blowing-in the blast furnace using heated nitrogen were developed and tested on BF No9. Thermo-technical basis of heated nitrogen application at the plant when blowing-in, work in unstable conditions on the requirements for the quantity of smelted iron, coke smelting without fuel additives to the blast and blowing-out of the furnace were substantiated [17, 20].

In the work "Design and development of loading modes, providing improved smelting performance when blowing of the blast furnaces of JSC" MISW" equipped with BLT" (Head – V. V. Lebed, 2013) recommendations for improving the efficiency of furnaces blowing aimed on the formation of efficient thermal condition of the lining and the cooling

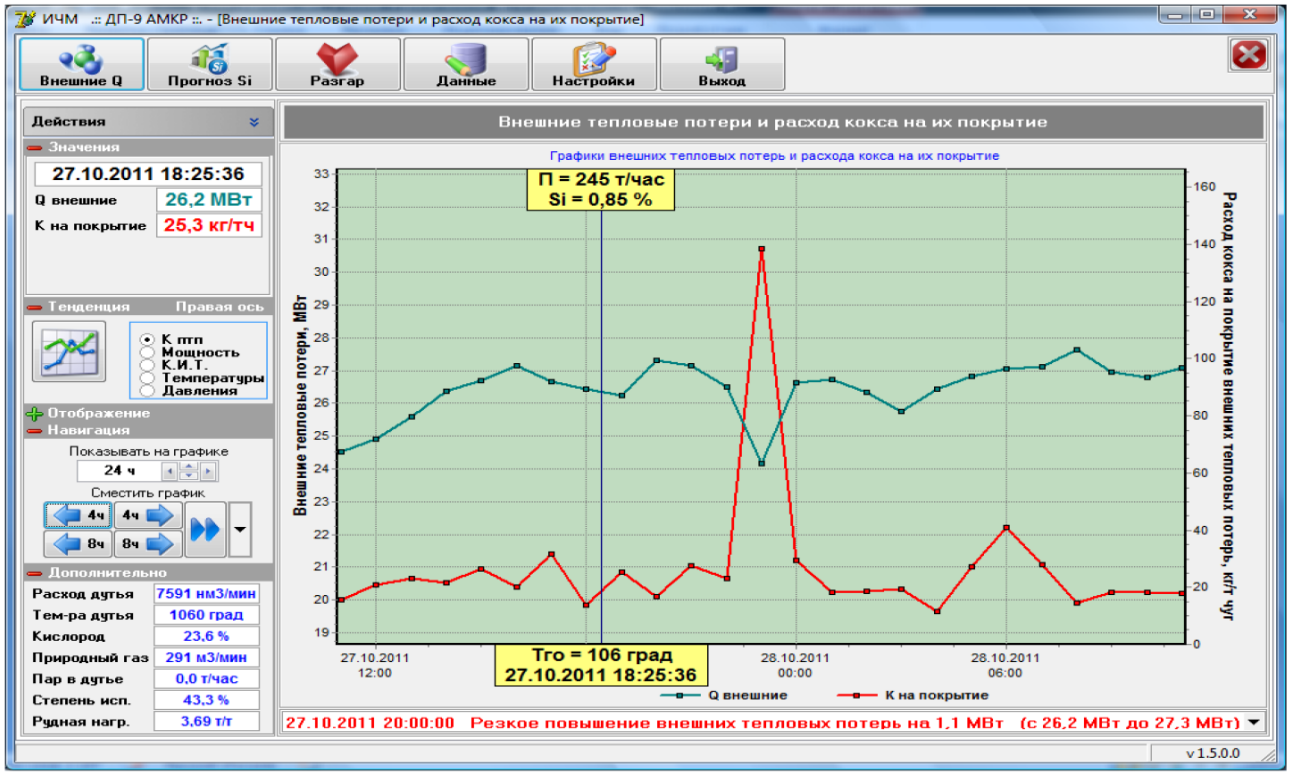


Figure 7. Video Snapshot of measuring external thermal losses (Q external) and coke consumption control on their covering (K on covering)

system operation, preventing the initial working section distortion of lining and ensuring the withdrawal of moisture from the furnace, normal heating of the column of charge materials and melting products without using natural gas, oxygen and steam up to the output of physically heated melting products were developed and successfully tested. The draft amendments to the technological instructions for drying, for blowing-in and blowing-out of blast furnaces of JSC "MISW" was developed.

In the work "Design and development of technical and technological measures that enhance the efficiency of the blast furnace No7 of JSC"NISW" (Head - V. I. Bolshakov, 2012), a set of measures providing increased smelting efficiency at BF No7 ("Rossiyanka") JSC "NISW" by improving the parameters and blast composition, thermal performance, loading mode and distribution of the gas flow was developed and implemented [21, 22]. The amendments draft to the technological instructions for conducting blast furnace smelting was made. The recommendations on forcing of and improving performance efficiency of BF "Rossiyanka" were developed.

In the period of carrying out the works on BF No7 the actual pig iron production increased by ~1700 tons /day to 10,700 tons /day, the average coke consumption was reduced by ~ 27 kg/t of pig iron to 409 kg/t of pig iron, the total fuel consumption was reduced by ~ 16 kg/t of pig iron to 488 kg/t pig iron, the total value of thermal losses in the cooling system was reduced by ~100 MJ /ton of pig iron to 316 MJ/ton of pig iron.

With regard to the mastering in 2012-2013 technology of blast furnace smelting in the BF "Rossiyanka" the method that allows to predict the rational combination of pressure under the top, temperature and top gas outlet has been developed (Fig. 8). [22] While maintaining the rate of top gas in the range of 0.9 ÷ 1.1 m/s and increasing of the furnace thermal capacity and the outlet of the top gas the increase of pig iron production can be expected, while maintaining the evenness of furnace run by rising the pressure under the furnace top. While maintaining the pressure under the furnace top at the same level the increase of pig iron production can be expected when keeping the evenness of furnace run by increasing the heat rat and top gas outlet in the case of its temperature reducing (Fig. 8).

Conclusion

In ISI of NASU the experience of successful development of advanced technologies in the blast furnace smelting with PCI on the blast furnaces of Ukraine, the inventions of design solutions for technical modernization of new and reconstructed blast furnaces accompanied by its commissioning on rational operation has been accumulated.

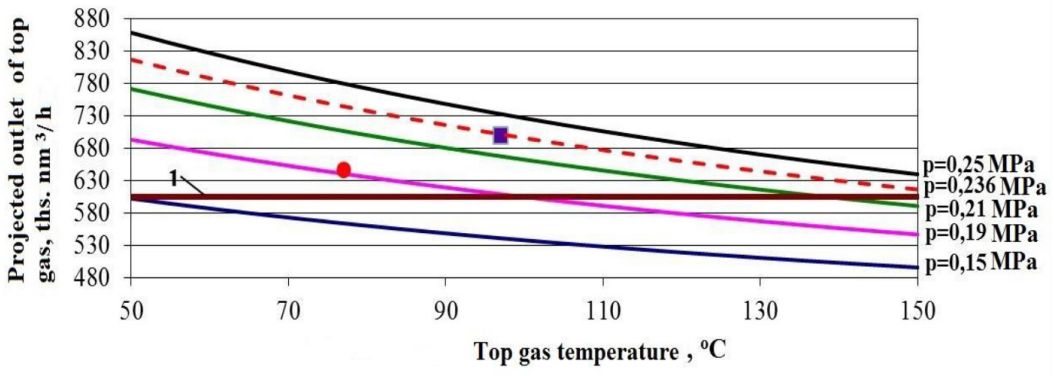


Figure 8. Projected variants of top gas outlet reduced to normal conditions, depending on the pressure (P) under the furnace top and its temperature while maintaining the top gas rate at the range of 0.9 ÷ 1.1 m/s. ● – base period (March 2013); ▮ – work during January 2013; 1 - project outlet of the top gas reduced to normal conditions

The successful development of blast furnace technology with PCI at the metallurgical enterprises of Ukraine requires the comprehensive review and decision, which covers not only the questions of improvement of charge conditions for the blast furnace and technical re-equipment of furnaces, but also the development of best management practices of blast furnaces thermal performance based on the burden distribution control, harmonization of thermal and gas-dynamic work of the top and bottom of furnace, the choice of parameters and the blast composition, organization of effective tuyere zone operation in the existing charge conditions of Ukraine with taking into account the technical condition of the furnace, the requirements for performance and quality of pig iron.

Blast furnace system reliability it is a new scientific direction that enables systematization of the development of thermal-technical and other ways of improvement of blast furnaces thermal performance and their design with application of different fuel additives to the blast.

References

1. Bolshakov V. I. Application of blast furnace technology with pulverized coal injection in Ukraine, Fundamental and applied problems of ferrous metallurgy: Procedings of scientific works, Kiev, *Naukova Dumka*, 2011, No23, p.p. 30 - 35.
2. Loginov V. I., Oreshkin G. G., Polovchenko I. G. and others, Pulverized coal injection into the hearth of the blast furnace, *Steel*, 1956, No8, p. p. 675 - 682.
3. Sieghardt W.C., Harris H.E., Finnery C.S. , Future Sources of Energy For Ironmaking, *Blast Furnace and Steel Plant*, No9, 1967, p.p. 809-815.
4. Nekrasov Z. I. 12 years of the combined application of blowing in blast furnace production of the USSR, *Metallurg*, 1970, No4, p.p. 29-32.
5. Bolshakov V. I., Chayka A. L., Lebed V. V. and others, Mastering of the blast furnace with useful volume of 3000 m³ using pulverized coal , *Metallurgical and Mining Industry*, 2012, No4, p.p. 36-40.
6. Bolshakov V. I., Chayka A. L., Lebed V. V., Experience and perspectives of pulverized coal application in the blast furnaces of Ukraine, *Metal and casting of Ukraine*, 2013, No10, p.p. 5-10.
7. Bolshakov V. I., Borodulin A. V. , Chayka A. L., The thermal performance and perspective constructions of the blast furnace shaft and metal reservoir when pulverized coal application, *Metallurgical and Mining Industry*, 2014, No 3, p.p. 106- 110.
8. Bolshakov V. I., Chayka A. L., Sokhatsky A. A., Tsyupa K. S., Goman S. V., Fomenko A. P., Pinchuk D. V. Prospects of development of automated control to ensure the reliability and efficiency of blast furnace smelting on the basis of information on the thermal performance of the shaft, Collection of scientific papers of IV interdisciplinary scientific and practical conference of young scientists and specialists in the design of mining and metallurgical complexes, energy and resources saving, the natural environment protection "Innovative ways of modernization of basic industries, energy and resource saving and natural environment protection", Kharkiv, March 25-26, 2015, p.p. 81 -85.
9. Nekrasov Z. I., Yubko L. D., Volovik A. V. The injection of pulverized coal in the hearth

of blast furnace of "Zaporizhstal" plant , "Investigation of the raw materials and processes of blast furnace smelting" (ISI) Proceedings of the Second scientific - technical conference of young researchers of ferrous metallurgy, October 15 – 18, 1968, Vol. XXXIII, Moscow, *Metallurgy*, 1971. p. p. 72 - 77.

10. Yaroshevskiy S. L. *Vyiplavka chuguna s primeneniem pyileugolnogo topliva* [Smelting of pig iron using pulverized coal], Moscow, Metallurgy, 1988, 176 p.
11. Semikin I. D. Use of natural gas in metallurgy, Report on republic section metallurgical furnaces: Use of oxygen, pulverized coal, and natural gas in blast furnaces, p. p. 36 – 42, Dnepropetrovsk, UkrNTO, 1957, 42 p.
12. Gladkov N. A. Fundamentals of developments of Zot Ilyich Nekrasov - Iron and Steel Institute after Z. I. Nekrasov, Dnepropetrovsk, ART - Press, 2007, p.p. 47-84.
13. Andronov V. N . *Sovremennaya domennaya plavka* [A modern blast-furnace smelting], St. Petersburg, Publishing House of the St. Petersburg of STU, 2001, 100 p.
14. Borodulin A.V., Gorbunov A. D., Romanenko V. I. *Domna v energeticheskom izmerenii* [Blast furnace in the energy measurement], Krivoy Rog, SP Mir, 2004, 413 p.
15. Borodulin A.V., C. P. Sushchev, AL Chayka On the development of scientific direction in metallurgy - system reliability of blast furnace, International scientific-technical conference "Theory and practice of pig iron production," dedicated to the 70th anniversary of KRMMP "Krivorozhstal", Kriviy Rig, 2004, p.p. 324 -328.
16. Patent of Ukraine for the invention 104228. A method for controlling the blast furnace run, Bolshakov V. I., Borodulin A. V. , Chayka A. L., Shvachka A. I., Registered in the State Register of patent for invention 10. 01.2014.
17. Bolshakov V. I., Sokhatsky A. A., Chayka A. L. , Shevelev A. G., Shvachka A. I. Researches of heat-gas-dynamic work in a "dry" zone of the blast furnace and application of their results, *Metallurgical and Mining Industry*, 2013, No2, p. p. 15-19.
18. Borodulin A. V., Sokhatsky A. A., Chayka A. L. Thermal-technical aspects of reducing energy consumption in metallurgy of pig iron: problems and prospects, The theory and practice of thermal processes in metallurgy, Collection of reports of International scientific - practical conference UrFU conference, Ekaterinburg, Russia, September 18-21, 2012, p. p. 57 - 66.
19. Bolshakov V. I. , Borodulin A. V., Chayka A. L., Shvachka A. G. Control of the total value of the thermal losses with cooling water in the furnaces of blast furnace shop and their applications, Proceedings of International scientific-practical conference "Theoretical heritage of V. E. Groom – Grzhimailo" dedicated to the 150th anniversary of V. E. Groom – Grzhimailo, UrFU, Ekaterinburg, Russia, March 26 - 29, 2014, p. p. 74 - 80.
20. Chayka A. L., Sokhatsky A. A., Listopadov V. S., Pinchuk D.V., Nyn S. V., Lukyanenko I. A. Heat and mass exchange in high-volume blast furnaces when blowing-in and the use of heated nitrogen, Proceedings of the VIII International Scientific Conference "Heat and mass exchange processes in the metallurgical systems", Mariupol, September 7-9, 2010, p.p. 237 - 244.
21. Kornilov B. V., Chayka A. L., Sokhatsky A. A., Shostak V. Y. Investigation of the influence of parameters of blast furnace gas and furnace top design on the flue dust discharge, Ecology and Industry, 2014, No2, No 54-58.