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Problems of coal gasification and gasification products usage in blast furnaces

I.G. Tovarovsky, A.E. Merkulov

Nekrasov Institute of Ferrous Metallurgy, National Academy of Sciences of Ukraine

Abstract

The implementation of national development of coke and all the injected natural gas (NG) replacement in a blast furnace (BF) with low-grade coal gasification products when using redundant BF for organizing of coal gasification process allows to reduce coke consumption to a level commensurate with the option of injecting the maximum number of pulverized coal, which has limited resources. Obtaining the fuel gases of energy use in blast furnaces meant to improve fuel balance of the enterprise and the region with simultaneous positive impact on the environment. Indicated developments are appropriate to include in a set of works planned by the leadership of the country in terms of imported natural gas substitution and involvement of low-grade coal of own extraction in the production operations.

Keywords: *gasification of coal, blast furnace, coal gasification products*

Currently, the consumption of natural gas in steel industry is about 4 billion m3 per year, one third is consumed by blast furnaces. Thus, in 2012 the price of natural gas is $ 484 per 1 thousand m^3, compared to $ 293 per 1 t of coke [1], what leads to higher prices for iron 484-0,7 · 293 = 279 UAH at the substitution equivalent of 0.7 kg/m^3 using each 1 thousand m^3 of gas.

When solving the problems of the coke consumption reduction one of the priorities is to implement a blast furnace technology with pulverized coal injection (PC), which found a widespread development on advanced enterprises of the world with the PC consumption of 250 kg/t of cast iron. Previously performed analytical studies have shown the possibility of coke consumption reduction to 280 kg/t of cast iron by blowing a specified amount of PC in separate blast furnaces (BF) of Ukraine taking into account the requirements for the ore and coke properties. However, the overall scale of development of this technology is limited primarily to higher quality requirements for coke and, respectively, for the coal-charge composition for coking as well as the coal mix for the PC manufacturing. At the request of Director General of the "Metallurgprom" associatioon V.S. Kharakhulakha: "Given the promising terms of construction for the PC injection in major metallurgical enterprises of Ukraine by 2015 it would be nice to receive annually coals of C, G, B types in the amount of 8 mln. tons, and, coal with low sulfur content and low ash content is required and with these requirements, Ukrainian coal miners can satisfy the needs of metallurgists only by 4 mln. tons per year. It is impossible to go without coal import of required quality" [2].

In case of the small PC discharges, limited by real conditions on the coke quality, iron ore and injected coal mix, the simultaneous injection of natural gas or other reducing gas is also required. Given the foregoing, the development of PC injection should be combined with the development of alternative coke replacement technologies [3].

The use of coke gas blown in through the blast tuyere is the most realistic among the possible gases replacing coke and natural gas of energy resources. This technology was developed at Makeevsky MP, where the cast iron of coke gas was blown in up to 250 m^3/t in BF from 1980 to 1992, which ensured the replacement of 100-120 m^3/t of cast iron of natural gas with reduced coke consumption by 30-50 kg/m of cast iron [4]. For implementation of the technology the complex structure of its preparation for blowing in blast furnaces is required for compression and cleaning of naphthalene, benzene hydrocarbons, hydrogen sulphide and nitrogen oxides.

The technology of partial replacement of coke by anthracite or thermoanthracite (which thermal resistance and mechanical strength are close to the coke characteristic and carbon content increases to 96-98% while reducing the volatile content to 0.3-0.8%) can be used in blast-furnace practice in Ukraine in case of lack of funds for the PC complex construction. Currently, the charging practice into BF of raw stone coal in the amount up to 100 kg/t of cast iron through the furnace mouth along the batch system of the stock main components is developed, which practically doesn't require any capital expenditures and provides an income for the difference in prices for coke and anthracite [5]. Investment opportunity in the complex construction for the PC injection will be created in parallel with the accumulation of funds. By the time the problem of natural gas replacement by coke gas will be largely solved, which will provide a more effective functioning of the PC injection technology.

The most effective solution to the problem of coke and natural gas replacement with limited coal resources of required mix can be obtained through the development of a new blast-furnace smelting technology using the gasification products of inferior coal (GPC). Demand for the specified development, started three decades ago by Nekrasov Institute of Ferrous Metallurgy, NAS of Ukraine (NIFM NASU) together with a number of specialized organizations, never caused doubts, however, an urgent need implementation is felt only now.

In August 2012 the President of Ukraine V.F. Yanukovich signed the law № 5189-V, increasing the amount of state guarantees to 30 billion UAH for attraction of credits from state banks of PRC. This amount lent to the State Development Bank of China, which is required for implementation of the replacement program of expensive Russian gas by the cheaper coal of Ukrainian mining. According to the press service of Ministry of Energy and Coal Industry in September, Minister of Energy and Coal Industry of Ukraine Yu.A. Boyko said: "Ukraine took a course on the imported gas replacement by Ukrainian alternative energy sources, especially the coal, which production volumes actively increase. Three coal gasification plants are planned to be built. We take the technology from the Shell company. This technology was tested in the Peoples Republic of China. Fifteen of such companies operate there. Three companies will be built in Ukraine, one in the Luhansk region, one in Donetsk and one in Odessa, for money of the China Development Bank. We practiced this mechanism for almost a year and will sign a loan agreement for this project in the end of November" [6].

Only some of more than sixty known gasification methods of solid fuels were developed. The main developers of corresponding technologies are Shell, Lurgi, British Gas, Texaco companies, and the All-Russian Thermal Engineering Institute, Institute of Fossil Fuels, Krzhizhanovskiy Institute of Energy, Research and Designing Institute for Problems of Development of Kansk-Achinsk Coal Basin "KATEKNIIugol", Moscow Institute of Steel and Alloys, Ukrainian State Research Institute of Carbochemistry, Donetsk National Technical University, Gas Institute of the NAS of Ukraine, Ukrainian State University of Chemical Technology, etc.

Most of developments related to coal gasification technology, are focused on the gasificator integration into the steam-gas cycle of power generation. The developments of technology of coal-derived gas production and use for metallurgy are also known.

1. The first stage of machines based on the Lurgi-type gas-producer unit rated at 960 thousand m3 of gas per day for the aluminum hydroxide burning [7], which was launched in 2007 in Pavlodar in JSC "Kazakhstan Aluminium" by SJSC "SUZMK ENERGO" in partnership with «ZVU Engineering» (Czech Republic).

2. The "Termokoks" technology for the production of combustible gas for energy or metallurgical purpose, developed by Russian specialists led by S.R. Islamov [8].

3. Semiproduction experimental plant of coal gasification in melted slag at Novolipetsk Metallurgical Combine and pilot plant at the research center in Taedzhon for the Samsung Heavy Industries company (South Korea),

created on the basis of Romelt process, the most important element of which is coal gasification by oxygen and iron oxides in the bubbling molten slag [9].

Due to the actualization of the problem of coal gasification products usage, it is necessary to refer to the results of the Nekrasov Institute of Ferrous Metallurgy developments together with a number of specialized organizations in relation to the blast-furnace smelting [10, 11]. Made within these works comparative evaluation of coal gasification methods from a perspective of the blast-furnace technology requirements (maximum and minimum gas temperature and minimum content of oxidants) showed the suitability of gasification methods in the flow through the cyclone and vortical devices, as well as in melted slag in a dense layer with slag tap.

There are two circuits of hot reducing gases (HRG) batch into the blast furnace, characterized by the gas-producer units set-up relatively to the blast furnace gas and their unit capacity: with a reducing gas batch from individual gasification reactors (GR) for each injection lance of BF; with the batch from one or more powerful GR through the circular gas pipeline into injection lances of BF. Both schemes have their advantages and disadvantages. A batch on the first scheme allows to lower the losses by reducing the length of hot gas pipeleading. It is better to organize the circumferential gas distribution, but the process of simultaneous control of gas-producer unit is complicated. Hydraulic and heat losses increase when batching on the second scheme, however, the use of higher power gas-producer units reduces energy losses in gas production and intermediate steps of gas processing (slag removal, decontamination, heating, compression) are possible.

Injection lance coal gasification (ILCG)

Gas-producer unit for energotechnological scheme of GR-injection lance is developed on the basis of gas-producer unit of pulverized coal of vortex type of Joint Institute for High Temperatures, Russian Academy of Sciences (JIHT RAS, Russia). Analytical and experimental studies to test the construction and working regime of gas-producer unit to obtain hot reducing gases for injection into blast furnaces were held in JIHT RAS and NIFM NASU for several years. The calculations and experimental studies showed the possibility of HRG obtaining with temperature up to 2000 °C and oxidants content of 1-2%, forming a protective scull of wanted thickness for the high resistance gas-producer unit based on GR of JIHT RAS compact gas-producer unit, which dimensions allow to install it within existing tuyere connections and operating in regime with the removal of the entire liquefied coal ash into the combustion zone along with obtained HRG. Reactor was dismantled and moved to the BF №2 of JSC "Tulachermet" after bench testing. Testing within two months showed the feasibility of development after some corrective actions of the reactor manufacturing.

Calculations on the model developed in the NIFM NASU were performed to analyze the features of the new technology and the expected results of (Table 1). Working conditions of the BF-9 PJSC "ArselorMittal Krivoy Rog" were taken as the base period. The PC option involves injection of 250 kg/t of cast iron of low-ash coal (up to 10% of ash, 13%of volatiles) and the GPC option - injection of HRG-GPC of high-ash coal (25% of ash, 25% of volatiles) in an amount of 400 kg of coal per 1 t of cast iron, assuming the replacement of coke amount close to the PC version

Table 1 Expected indicators of the blast-furnace smelting at the 5000 m^3 BF of PJSC "AMKR" with PC injection, GPC-HRG and the coke consumption minimization (Cmin) by increasing the temperature of air blasting and raw limestone transfer from the blast-furnace burden to the sintering mixture.

Indicators	**Basis**	**PC_{250}**	**GPC_{400}**	**$GPC_{400}C_{min}$**
Daily production, t/d.	9604	9170	7910	9012
Coke consumption, kg/t of cast iron	483	308	342	250
Air blasting: consumption, m^3/min	6674	6389	3060	2172
temperature, °C	1090	1090	1090	1300
oxygen content, %	30.5	30.5	30.5	30.5

Natural gas consumption, m^3/t	87	0	0	0
Injected coal consumption, kg/t	0	250	400	400
HRG-GPC: amount, m^3/t of cast iron	0	0	1106	1106
temperature, °C	-	-	1590	1693
$CO+H_2$ content, %	-	-	60.3	60.3
Top gas: temperature, °C	81	308	289	185
content, %: CO	29.1	27.9	29.3	28.3
CO_2	19.8	22.4	19.0	19.9
H_2	7.7	5.0	8.3	9.2
Limestone / convert. slag, kg/t	35/56	47/56	132/55	0/57
Amount of slag, kg/t	416	445	550	545
Oxygen consumption (calc.), m^3/t	141	142	79	49
Theoretical combustion temperature, °C	2219	2328	2056	2054
Direct reduction of the oxide Fe, %	35.9	33.1	22.0	28.3
Use of $CO+H_2$, %	40.5	44.4	39.1	41.3
Total heat input, kJ/kg	4425	4917	5314	4617
Consumptive use of heat, kJ/kg	3899	3846	3777	3591
Heat losses, kJ/kg	302	247	373	388

Analytical and experimental studies of injection lance coal gasification revealed regularities of processes and allowed to develop a number of new technical solutions as inventions that formed the basis of a new blast-furnace smelting technology [10, 11].

Blast-furnace coal gasification

This scheme of HRG batching involves getting all the gas required for the blast-furnace smelting, in one high-performance gasificator with its distribution on the injection lances. One of the furnaces of blastfurnace plant, turned to the working regime of gas-producer unit can be used as gasificator. Two options are possible depending on the method used: 1 - layered gas-producer unit - LGPU, 2 - liquid-phase gas-producer unit - LFGPU.

1. BF is reconstructed to the gas-producer unit (LGPU) of non-coking coal by its equipping with additional shoulders, gas flue channels and hot reducing gas collector. Additional shoulders are located near the bottom of the stack and furnace waist and designed for the separation of gas-producer unit into two zones: the upper - stock preparation zone and the lower charge - batch handling zone with HRG obtaining [12].

Stock heating and the removal of absorbed moisture (HRG ballast) is performed in the upper zone of LGPU. The process of HRG getting through the air-steam coal gasification with ash tapping is performed in the lower zone. Additional shoulders form a restful zone (gas chamber) of HRG in front of gas flue fittings and collector and manifold pressure and reduces the pressure of melting stock column located in the preparation zone, on the reactive with the steam-air blow layer in the treatment zone. Coal gasification by hot atmospheric blowing is carried out on the injection lances of LGPU to maintain the theoretical combustion temperature of 1900-2000 °C to form the rational temperature field in chimney of LGPU, providing forming and removal of liquid products (slag and cast iron) and the temperature of produced HRG at 1200 °C. The main part of the generated HRG is selected from the annular vugh formed by the surfaces of riser pad and the furnace wall, and is directed for blowing into the blast furnace. The other (small) part of the gas goes through the lower part of the annular vugh for the preparation of melting stocks and is removed from the shaft furnace through the mouth. Lump candle coal, for example, of types M, C, A, L of size 5-50 mm is recommended as a base of coal gas-producer unit.

2. LFGPU: the achievement of high performance of HRG obtaining is also possible on the basis of technology of coal gasification in a liquid bath. The choice of reactive atmosphere quality of melted slag enables a high temperature level, and hence a high productivity of the process, substantial environmental benefits and

ease of construction of the main equipment. Furthermore, during the coal gasification it is possible to use almost any type of coal without any limitations in composition, humidity and size on the same equipment. Steelmaking slags containing CaO and iron oxides may be used as a flux metal in the gasifier installation at metallurgical plant. The output of cast iron will increase significantly and, as a result, a share of expenses on fuel for the production of HRG can be covered by coproducts. Fuel underburning is completely excluded during the gasification of coal melted slag. Testing of coal gasification technology in the melted slag was carried out on a pilot plant Romelt of Novolipetsk steel mill, on which the HRG was obtained with the temperature of 1200 °C and the CO + H2 content up to 90 % [13].

A complex of analytical studies by varying the blast parameters in a wide range: oxygen from 21 to 90%; temperature from 1300 to 100 °C was performed to analyze the influence of coal gasification parameters on the formation of composition and properties of the injected into the blast furnace through the injection lances of GPC as well as the final indicators of blast-furnace smelting. The GPC blowing in BF without ash that remains in gasificator is the feature of coal gasification in the blast-furnace gasificator. Table 2 shows the main estimate indicators and parameters of processes for BF № 9 of PJSC "ArselorMittal Krivoy Rog" for various parameters of the air blasting for coal gasification in blast-furnace gasificator and the air blasting for coke gasification on furnace injection lances. In versions 1-3 the oxygen concentration was increased and the blast temperature of gasificator was reduced, in versions 4 and 5 the coal was gasified by atmospheric blast with the highest possible temperature during the blowing of hot blast in vers. 4 and cold oxygen in vers. 5 into the blast furnace.

Table 2 Estimate indicators and parameters of smelting in the BF № 9 of PJSC "AMKR"

Indicators	**Vers. 1**	**Vers. 2**	**Vers. 3**	**Vers. 4**	**Vers. 5**
Specific productivity, t/(m^3·d.)	1.37	1.51	1.56	1.38	1.44
Coke consumption, kg/t of cast iron	251	267	291	187	221
Air blowing for blast furnace: consumption, m^3/min	1799	2249	2763	861	457
temperature, °C	1100	1100	1100	1300	100
oxygen content, %	27	27	27	30	90
Tech. oxygen consumption, m^3/t	33	38	45	23	90
Loaded coal into the gasificator, kg/t of cast iron	400	400	400	400	400
Air blowing for coal gasification: consumption, m^3/kg	2.34	1.59	1.06	3.02	3.02
temperature, °C	1100	700	100	1300	1300
content: O_2, %	27	40	60	21	21
Oxidizing compound coefficient mole O/mole C	0.5	0.5	0.5	0.5	0.5
GPC: amount, m^3/t of cast iron	1188	959	799	1395	1395
temperature, °C	1577	1563	1567	1595	1595
CO+H_2 content, %	56	69	83	48	48
Top gas: temperature, °C	177	120	141	97	97
content, %: CO	25.0	28.9	32.1	20.5	24.0
CO_2	19.1	21.5	23.0	19.1	20.3
H_2	8.6	9.6	10.2	8.0	8.7
Amount of slag, kg/t	429	429	431	426	427
Theoretical combustion temperature, °C	1879	1946	2034	1787	1870
Amount of dry top gas, m^3/t	1679	1517	1459	1620	1565
Direct reduction of oxide Fe, %	24.2	23.1	21.3	24.2	23.3
Use of CO+H_2, %	43.3	42.7	41.7	48.3	45.9

Total temperature input, kJ/kg	4470	4144	4130	4240	4214
including: coke burning	1085	1235	1466	570	862
blast and additives heat	3278	2801	2556	3565	3246
Heat requirement, kJ/kg	3431	3396	3343	3458	3443
Top gas enthalpy, kJ/kg	641	377	413	361	357
Heat losses, kJ/kg	398	372	375	420	414
Top gas calorific value, kJ/m^3	4093	4698	5165	3455	3981
Intensity: by coke, kg/m^3·d.	337	393	444	254	312

On the basis of calculation results it was found that blast enrichment for coal gasification by oxygen up to 40-60% allows to get a high-potential HRG, which injection into the blast furnace, however, turned up less effective than injection of HRG, obtained in the atmospheric blast with the highest-possible temperature. The task of performance improving, when required is solved by the oxygen supply in the air blasting of blast furnace (vers. 5).

The developments of blast furnaces placement under a regime of gas-producer unit for obtaining of reducing gas suitable for use in industrial and energy units as high-calorific fuel are carried in the NIFM NASU. At present there are 36 BF in Ukraine, among which 28 units are in operation. There are 3 furnaces in a reserve of metallurgical combines, 4 BF are planned to be deducted by 2014. In such conjunctural circumstances, these BF can be suitable to perform the coal gasification.

Meagre and stone coal, which are accessible enough and depose a small amount of tar should be chosen as the coal for gasification. The possibility to use the solid lump materials, loaded with coal is the feature to use a blast furnace as a gas-producer unit [10, 11, 14]. These materials contain fluxing agents and other useful components extractable into the liquid-alloys (cast iron and slag) formed as coproducts in the coal gasification. For these purposes it is expedient to use metallurgical slags - converter, welding, ferromanganese, silicomanganese by extracting the useful components into the liquid-alloy. In this way, economic and environmental problems of industries are solved along with the energy problems. The important technological problem is solved by the use of metallurgical slags: as they do not contain easy-remanufacturable oxides, giving up oxygen in the stack in "indirect" way, the exhaust gas is not appended by recovery gaseous products (CO2 and H2O), which reduce its caloric value. Obtained during the smelting metal contains up to 20% of manganese when setting a self-fluxing mixture of silicomanganese, ferromanganese and converter slag into the stock. It can be added to the cast iron of other blast furnaces with the removal of manganese additives from the stocks of these furnaces, saving the coke.

Thus, the complex work on the use of the BF as multifunctional units to solve the energy, environmental and related socio-economic problems of industry and region is done by improving the technology in the course of solving the problem of coke and natural gas replacement in blast-furnace smelting. It is expedient to include home-grown technologies in the set of works planned by the nation's leadership in terms of the imported natural gas replacement and the low-grade coal of equity production involvement in the production turnover.

Conclusions

Complex development, which implementation will not only solve the problem, but also have a positive impact on the energy, environmental and related socio-economic problems of industry and region was performed in terms of the solution of complex problems of the coke consumption reduction and natural gas replacement in blast-furnace smelting of NIFM NASU together with other organizations.

It is hown that the part of coke and all injected natural gas replacement by gasification products of low-grade coal in the operating BF using extra blast furnaces for the coal gasification processes organization will reduce the coke consumption to a level commensurate with a version of the maximum injection of maximum amount of pulverized coal, which resources are limited. Getting the fuel gas of energy purposes in some BF should improve the fuel balance of industry and region with the simultaneous positive impact on the environment.

It is expedient to include home-grown technologies in the set of works planned by the nation's leadership in terms of the imported natural gas replacement and the low-grade coal of equity production involvement in the production turnover.

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