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Transfer of Operating Coke Battery to Loading with Stamped Charge

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Abstract

It is known that the production of blast furnace coke using stamping technology allows the use of a large amount of cheap gas coal without reducing the quality of the blast furnace coke obtained. However, despite the fact that this coking technology has been used for a long time, the literature data as per the effect of increasing density on coke quality parameters are very scarce and outdated. Furthermore, the findings in these articles are sometimes contradictory. Taking into account the above, the purpose of the study was to verify the appropriate cost-effectiveness and efficiency of coke production while optimizing the consumption of scarce raw materials, which would allow optimizing production in the conditions of an operating coke chemical enterprise. The article describes the main technical solutions for transferring the operating coke battery from the technology of loading coking chambers by gravity to the technology of loading stamped coal cake and gives the results of the reconstructed coke battery. This project was developed and implemented by the companies SE GIPROKOKS and HuDe. The economic and technological indicators of coke quality as a result of the transfer of the operating coke battery to the stamped coal cake loading technology compared to its operation parameters using the gravity loading method of coking chambers were considered and compared. It is shown that during the control observation period (19 months) of the enterprise's operation, the mechanical strength of coke M_{25} increased from 85.2 to 87.4% on average; the coke strength after reaction CSR - from 48.9 to 53.9%; at the same time, the index M_{10} was decreased from 8.0 to 5.9%; and CRI - from 38.0 to 37.2%, respectively, when working with the stamping technology compared to operation with the gravity method technology. Also, coke obtained using the charge stamping method is characterized by lower values of ash content and total sulfur content.

Keywords: *Coke battery; Stamping technology; Gravity method; Compaction; Coal cake.*

1. Introduction

The problem of coke quality changes the key role in the operation of blast furnaces - the main recipient and consumer of coke [1-3]. Coke in the blast furnace process performs the following functions: energy provider (provides the process with heat), chemical reducer (source of reducing gases and carbon for iron recovery) and physical supporter (supporting the column of charge materials, ensuring the flow of gas through the furnace charge and the flow of liquid metal in the lower part of the furnace). The dynamic technological development of the steel industry, which has been observed in the last decades, including the operation of blast furnaces with increasing volume and the use of alternative fuels (pulverized coal, liquid fuels and natural gas), has led to an increase in the importance of the physical role of coke and, as due to the requirements for its strength parameters [4-6]. That is why the key role is currently assigned to coke quality parameters evaluated by the NSC (Nippon Steel Corporation) method, i.e. CRI (coke reactivity index) and CSR (coke strength after reaction) [7-9].

Achieving the necessary indicators of coke quality by producers requires the use of a large amount of coking coals of the highest quality in the coal blend, which significantly increases the unit production cost. Approximately 75% of these costs are the costs for preparing the coal mixture [2]. In general, there is a shortage of coking coal of the best quality on the world market, and its supply is characterized by large fluctuations in quality parameters. Coking coal is more than 50% expensive than low-grade coal [10-11]. Taking into account the above, it is expedient to carry out research on the optimization of blast furnace coke production using stamping technology, due to the fact that this technology allows the use of a large amount of cheap gas coals, including oxidized ones [12-15] without reducing the quality of the obtained blast furnace coke.

As a result of the cooperation of SE GIPROKOKS with the leading German manufacturer of coke machines and equipment, a unique project was elaborated to retrofit an operating coke battery, initially designed for gravity charging, with technological equipment that realizes the loading of stamped coal cake. It is known that the technology of stamping (compaction) of coal charge allows to significantly reducing the proportion of well-caking coal in the charge. For the traditional coking process (coke ovens with gravity loading), it is necessary to use at least 65% of well-caking coal in the charge. When coking the stamped charge, this indicator is reduced by approximately half.

The advantages of the chosen technology are also the following:

- the use of cheaper and easily available coals (with a high content of volatile matter and low cakability);
- expansion of the raw material base;
- achievement of similar or higher quality indicators of coke obtained from stamped charge compared with the coke produced in a coke oven using a gravity charging method;
- increasing the coke output from the coking chamber;
- increasing the productivity of blast furnaces and the efficiency of the blast furnace process when using coke produced from stamped charge.

Stamping technology is used on newly built or replaced facilities (including changing the production system from top to stamping loading). Of all available methods, the stamping method gives the best results of increasing the density of a coal charge. The bulk density achieved in this case can exceed 1100 kg/m^3 (on wet state), while in the case of the top charging system it is at the level of 780-820 kg/m^3. Moreover, this technology does not require the use of additional liquid materials to increase the bulk density [16-17].

Previous studies have established that the use of stamp-charging technology allows obtaining blast furnace coke of higher quality, both in terms of mechanical strength (M_{25} and M_{10}), as well as CRI and CSR [18-21]].

The application of the above method also has a positive effect on the environmental friendliness of coke production - due to the increased coke battery productivity, the specific emissions of harmful substances into the environment decrease. Therefore, in recent years there has been an increased interest in this technology, which is expressed in the construction of coke batteries with the stamp-charging technology, both in Europe (Germany, Poland, the Czech Republic, Ukraine) and in the East (China and India) [22-23].

The technology of stamping (compacting) coal before loading it into the chamber is known and used in many countries, while it has a different design and set of equipment.

However, until now, all coke battery complexes working on stamping technology were designed according to a separate design that took into account a number of limiting factors that arise in the production of coke from a stamped charge. One of the main limiting factors for converting coke batteries from gravity loading to stamping technology is the difficulty of ensuring the stability of the stamped coal cake. It is difficult to achieve stability of the stamped cake when increasing its height without significantly increasing the width of the stamped cake.

The purpose of the project elaboration of the coal charge stamping technology for the complex of coke batteries, which were not originally designed for loading the stamped charge, is the possibility of obtaining higher quality coke on these batteries, even when using lower quality coals. The company HuDe (Germany), one of the world leaders in this field, acted as a supplier of coal stamping technology. When implementing the stamping technology, the possibility of battery operation using the technology of gravity charging of coke chambers is preserved, if necessary.

2. Methods and materials

2.1. Raw materials

In the Tables 1–2 it is shown the grade and component composition of gravity and stamped coal charge respectively for the control period of observations (19 months).

Table 1. Grade composition of bulk coal charge (top charging).

Grade of coal	A month of observation									
	1	2	3	4	5	6	7	8	9	10
G	25,08	24,67	24,74	24,98	25,53	28,12	26,15	24,67	20,17	25,0
Zh	21,91	23,69	28,73	19,9	24,12	19,5	21,94	29,32	27,54	25,1
C	49,1	43,37	42,02	47,55	41,73	46,42	42,65	37,86	43,18	36,3
L	3,91	8,27	4,51	7,57	8,62	5,96	9,26	8,15	9,14	13,6
Total	100	100	100	100	100	100	100	100	100	100

Grade of coal	A month of observation								
	11	12	13	14	15	16	17	18	19
G	25,0	25,1	27,0	29,9	31,9	30,9	28,6	32,7	29,9
Zh	30,0	22,0	26,6	19,1	14,5	23,8	20,2	20,3	27,5
C	32,5	44,5	35,8	36,4	40,7	26,1	32,0	35,3	30,9
L	12,5	8,4	10,6	14,6	12,9	19,2	19,2	11,7	11,7
Total	100	100	100	100	100	100	100	100	100

Table 2. Grade composition of stamped coal charge

Grade of coal	A month of observation									
	1	2	3	4	5	6	7	8	9	10
G	0	59,6	60,01	59,83	60,1	57,33	59,06	60,2	59,9	59,8
Zh	0	15,33	14,81	12,7	11,48	12,36	17,35	17,01	20,2	20,2
C	0	20,15	16,72	13,05	16,09	18,12	5,87	2,7	0	0
L	0	4,92	8,46	14,42	12,33	12,19	17,72	20,09	19,9	20
Total	0	100	100	100	100	100	100	100	100	100

Grade of coal	A month of observation								
	11	12	13	14	15	16	17	18	19
G	59,5	59,4	60,1	60,7	63,5	62,4	58,7	55,5	54,0
Zh	20,3	20,2	19,7	18,5	14,5	14,9	16,7	20,1	17,8
C	0	0	0	0	0	0	0	0	5,7
L	20,2	20,4	20,2	20,8	22	22,7	24,6	24,4	22,5
Total	100	100	100	100	100	100	100	100	100

During the specified period, the production charge, which was loaded by the traditional gravity method, included 5 gas-type coal concentrates, 9 fatty-type coal concentrates, 15 coking-type coals, and 4 lean-type coals. During the same period, the stamped charge included up to 4 gas-type coal concentrates, 8 fatty-type coals, 11 coking coals, and 4 lean-type coals. The component composition is formed according to the supply contracts of the enterprise.

As one can see, gravity and stamped charges differ significantly in terms of their quality composition. Thus, the gas coal content of the gravity charge ranged from 20.17 to 32.70%; fat coals - from 14.50 to 30.00%; coking coals - from 20.10 to 49.10%; lean coals - from 3.91 to 19.20%. Instead, we can observe a significant increase in the content of gas coals in the stamped charge - from 54.0 to 63.5%; the content of lean coals was also increased from 4.82 to 24.60%; at the same time, the content of well-caking coals was decreased - fatty coals from 11.48 to 20.3% and coking coals - from 0 to 20.15%.

The indicated difference in the basin affiliation of coal concentrates included in the composition of coal charges used in the production of coke using the methods of gravity and stamped loading of the charge was a consequence of the differences in the quality requirements of coal charges prepared by the gravity and stamped method (Tables 3–4).

Table 3. Technological properties of bulk coal charge (top charging).

Value	Proximate analysis, %				Bulk density, t/m^3		Plastometric indexes, mm		Granular composition (mm), %			
	W^r_t	A^d	S_t^d	V^{daf}	Fact.	Dry	x	y	<0,16	<3,0	3–6	>6
Maximum	9,6	8,9	0,80	31,0	0,800	0,739	37,0	17,0	19,6	81,2	12,4	10,0
Minimal	7,5	8,2	0,46	29,2	0,781	0,708	32,0	17,0	16,8	79,7	9,8	6,8
Average	8,5	8,5	0,60	30,1	0,790	0,724	35,0	17,0	18,4	80,4	11,6	8,1

Table 4. Technological properties of stamped coal charge.

Value	Proximate analysis, %				Bulk density, t/m^3		Plastometric indexes, mm		Granular composition (mm), %			
	W^r_t	A^d	S_t^d	V^{daf}	Fact.	Dry	x	y	<0,16	<3,0	3–6	>6
Maximum	11,9	8,3	0,54	33,3	1,154	1,017	46	14	23,7	92,1	8,0	1,5
Minimal	10,8	7,6	0,42	31,5	1,072	1,014	42	13	20,0	90,7	6,7	0,9
Average	11,5	8,0	0,50	32,5	1,145	1,017	45	14	21,9	91,5	7,3	1,2

In particular, compared to the charge loaded into the coking chamber by gravity, the charge for stamping is characterized (on average) by high values of moisture (11.5 vs 8.5%), yield of volatile matters (32.5 vs 30.1%), bulk density (1.145 vs 0.790 t/m3), content class <3.0 mm (91.5 vs 76.8 %). On the contrary, top coal charge is characterized by a higher level of plastic layer thickness, y (14 vs 17 mm).

2.2. Methods

To determine the quality indicators of coals, coal blends and obtained blast-furnace coke, the following standard methods were used:
ISO 17246:2010 Coal — Proximate analysis; ISO 18283:2022 Coal and coke — Manual sampling;ISO 17247:2020 Coal and coke — Ultimate analysis;ISO 334:2020 Coal and coke — Determination of total sulfur;ISO 1170:2020 Coal and coke — Calculation of analyses to different bases;ISO 7404-5:2009 Methods for the petrographic analysis of coals — Part 5: Method of determining microscopically the reflectance of vitrinite;ISO 7404-3:2009 Methods for the petrographic analysis of coals — Part 3: Method of determining maceral group composition;ISO 18894:2018 Coke — Determination of coke reactivity index (CRI) and coke strength after reaction (CSR); SO 1953:2015 Hard coal – Size analysis by sieving; DSTU 7722:2015 Hard Coal. Method for determination of plastometric indexes.

For the elaboration of the project, a model of a heavy-duty oven was chosen, which, on the one hand, has the best indicator in terms of the ratio of investment to productivity, but on the other hand, requires non-standard solutions or the method of stamping and loading coal cakes.

The main parameters of the coke battery are given in Table 5. The parameters of the stamped coal cake are presented in Table 6.

Attention should be paid to the indicators of the height of the coking chamber and coal cake. The preparation of a coal cake with a height of more than 6.5 meters and a width of 415 mm is a complex technological task. New technical solutions were adopted in the design of coking machines, which were revised during the start-up and adjustment works.

The main device for preparing a stamped coal cake is a stamping trolley mechanism provided with falling rods with stamping hammers. This mechanism has special requirements. On the one hand, to ensure the stability of the coal cake, the mechanism must provide sufficient stamping energy and, accordingly, have an increased weight of stamping hammers compared to existing analogues. On the other hand, the mechanism must provide a high speed of raising the stamming rods, which allows to fit into the cyclogram of preparation and loading of the coke oven.

Table 5. The main parameters of the coke battery.

Name of indicators	Unit	Value
Heating system	PVR, heating with coke gas	
Heating gas supply	lower	
The number of ovens in the battery	pcs.	41x2
The volume of the coke oven	m^3	51,0
Coke oven sizes:		
total length	mm	16820/17056*
useful	mm	15980
total height	mm	7000/7100*
useful	mm	6700
the width of the oven is average	mm	480/465*
The width of the front part is average	mm	1090
Taper	mm	50
The thickness of the heating wall	mm	105
The distance between the axes of the ovens	mm	1570
Coking period	hours	22,5
Productivity of the coke battery based on coke of 6% humidity	thousand t/year	1140

** - indicators in a hot state*

Table 6. Parameters of stamped coal cake.

Name of indicators	Unit	Value
The dimensions of the stamped coal cake:		
Length	mm	15982
Height	mm	6515
Width	mm	415
The volume of the coal cake	m^3	43,21
Density of coal cake:		
- 11% humidity	t/m^3	1,16
- on dry state		1,032

As a result, the task of preparing a coal cake was successfully solved during the elaboration of this project.

To solve the complex task of ensuring the loading of coal cake into the chambers, taking into account their current condition, a unique system was developed together with specialists from HuDe (Germany), which allows, without manual readjustment of the mechanisms of the loading machine, to automatically adapt the height and slope of the landing tray according to geometric characteristics of each chamber separately. The parameters are recorded in the machine's memory and are automatically set when the next coke chamber is selected for operation.

The pictures below show pictures of the installed stamping machine (Fig. 1 – external view, Fig. 2 – internal view). In Fig. 3 shows the general layout of the stamping machine installation.

As the density of coal charge in the coking chamber is increased when putting into operation the coal charge stamping technology, the coking period compared to the traditional top-charged technology was increased up to 22.5 hours. The capacity of the coke battery during this period of coking remains at the previous level and amounts to 1.14 million tons of coke of 6% moisture per year.

When loading the operating coke battery with stamped charge, all facilities of the infra-structure of the battery are fully preserved with the addition of facilities necessary for the stamping technology, as well as the reconstruction of some existing building structures. Implementation of the coal charge stamping technology is carried out in the conditions of the operating coke plant.

Fig. 1. Stamping machine. View from the outside.

Fig. 2. Stamping machine. View from the inside.

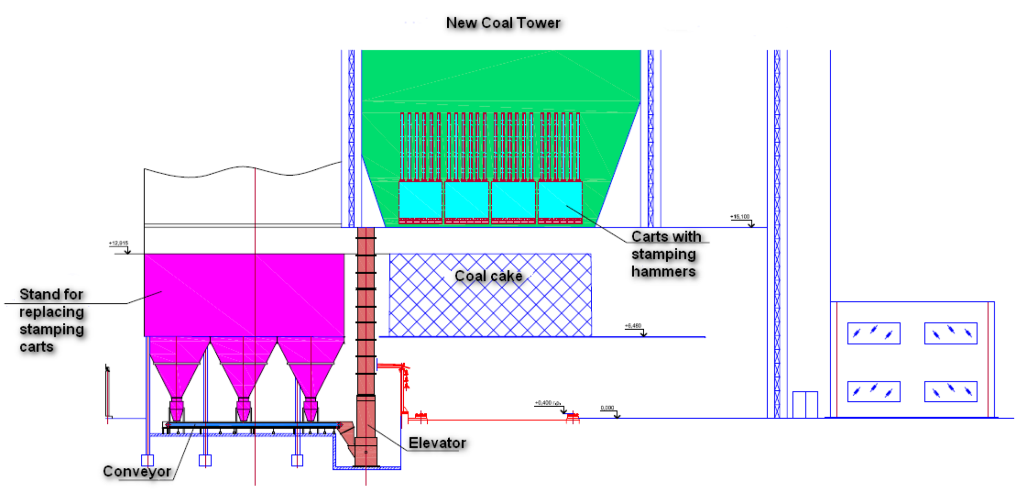

Fig. 3. General plan diagram of the stamping machine installation

To provide the coke battery with a coal charge suitable for stamping, the existing facilities of the coal preparation plant are used, which provide reception and storage of incoming coals, their dosage and final grinding.

In the existing coal crushing department, the components of the coal charge were implemented with technical solutions for crushing them with hammer crushers to a size of 90%+1% of the class less than 3.15 mm and for moistening with further control of its humidity along the supply conveyor to the coal tower [24].

- After grinding, the charge is directed to a new coal tower equipped with stationary stamping facility in its lower part using a tubular conveyor (which allows to avoid additional costs for the construction of transfer stations). Blocked with the operating rooms of the coal tower is the room of the stand for replacing stamping carts trolleys and repairing stamping rods, which have common paths for moving stamping carts.
- The stamped cake is transported and loaded into the coking chamber by a new loading machine.
- The coal cake is fed into the coke oven on a tray together with a locking rack that is locked with it, which performs the function of the rear wall of the stamping box during stamping.
- In the process of stamping and loading the coal cake, the eventual spills of the coal charge enter the belt conveyor, located under the stamping box of the loading machine, and are periodically discharged into the storage tank with subsequent removal by a truck.
- A coke pusher is used to push coke from the coke ovens.
- To ensure the correct operation of the new loading machine, its exact fixation when placed at the coke oven, the reconstruction of the coke pusher paths is provided, with the installation of tight rails.
- Repair and maintenance of a set of coke machines (coke pusher and loading machine) is planned at the new terminal site.
- The modernized battery is equipped with new, modern and efficient systems for collecting and cleaning gases emitted during loading and servicing the ovens installed both on the new loading machine and on the existing coke pusher.
- After the transfer of the coke battery to the coal charge stamping technology, the possibility of coke battery operation with the use of top charging technology remains.

3. Results and discussion

Tables 7 and 8 represent technological properties, strength indicators, as well as indicators CSR and CRI of coke produced from top and stamped coal charges.

Table 7. Technological properties, strength indicators and indicators of reactivity of cokes from top coal charge.

Value	Proximate analysis, %		Mechanical strength		Reactivity and strength after reaction, %	
	A^d	S_t^d	M_{25}	M_{10}	CSR	CRI
Maximum	12,4	0,7	86,5	8,4	52,2	40,0
Minimal	11,2	0,4	84,0	7,8	46,6	36,0
Average	11,6	0,5	85,2	8,0	48,9	38,0

Table 8. Technological properties, strength indicators and indicators of reactivity of cokes from stamped coal charge.

Value	Proximate analysis, %		Mechanical strength		Reactivity and strength after reaction, %	
	A^d	S_t^d	M_{25}	M_{10}	CSR	CRI
Maximum	12,0	0,5	89,3	6,9	58,1	39,3
Minimal	10,5	0,4	85,5	5,5	49,3	36,0
Average	11,3	0,4	87,4	5,9	53,9	37,8

Analyzing the data of Tables 7 and 8, it is evident to conclude about a significant improvement of all investigated quality indicators of coke obtained using the charge stamping method compared to the top charging one. Thus, the mechanical strength M25 was increased by an average of 2.2%, and CSR – by 5.0%, while the average indicators M10 and CRI, on the contrary, were decreased by 2.01 and 0.2%, respectively. Also, coke produced using the stamp charging method is characterized by lower values of ash content (0.3%) and total sulfur content (0.1%).

The results obtained are maximally consistent with similar studies that were conducted in Australia at the Illawara Coke Company (ICC) [25]. Compared to the coke obtained from the gravity charge, the coke obtained from the stamped charge was characterized by a slightly higher value of the CSR index and a similar value of the CRI index. On the other hand, evaluation of the effect of coal charge density on coke quality during industrial tests at the Sesa Kembla coke plant (the non-recovery coke plant in India) [26] did not show changes in CSR and CRI indicators. Coke obtained from a compacted coal charge was characterized by a similar value of NSC indicators, as in the case of the gravity system. In [27], the study was conducted in a pilot furnace using an industrial charge for a charge with a density of 926 and 996 kg/m3. It was established that the increase in density in the studied range had a positive effect on the CSR index, which was increased from 57.5 to 62.9%.

The positive effect of using stamping technology (in relation to gravity one) was observed in [28]. Tests were conducted for three types of coal blends. Coke produced from stamped coal blends was characterized by a higher value of the CSR index and a lower value of the CRI index. Other researchers [29] found that coke obtained using the stamping technology was characterized by a similar value of the CRI index and a higher CSR index.

In the widely available literature, there is no information about the influence of the content of low-caking coal in the coke mixture on the texture and structure parameters that form the coke quality parameters.

As for the coke quality parameter M10, there is general agreement that it is improved with compaction of the coal charge [30-32], while for M40(25) the authors conclude that stamping of the coal charge (i.e., increasing its density) in some cases improves the quality of coke [31,33], and in some it does not improve or may even worsen the quality [30].

It should be noted that the average market price of coal charge for the top charging technology was $349.0/t, and that of coals for stamp charging one was $316.5/t. Therefore, the use of stamping technology allows to reduce the cost of coal charge by $32.5/t.

4. Conclusions

SE GIPROKOKS and the HuDe company have elaborated and implemented the project to transfer the operating coke battery from the gravity method of coke ovens charging to the technology of stamped coal cake loading. The adopted decisions made it possible to implement the project with maximum preservation of the existing infrastructure and a minimum set of additional facilities. At the same time, the possibility of operation using coke battery top loading according to the traditional technology is preserved, in case of changes in the conditions of the raw material base for coking. In the process of engineering and implementation, a number of new technical solutions were implemented, which allow to ensure stable and successful operation of the equipment and structures of the coke battery and the adjacent infrastructure. The height of the coking chamber is 7 meters with an average width of 480 mm, making this project unique for modern stamping technology on a global scale. The use of stamping technology made it possible to increase the content of low-caking highly-volatile coals (G, GZh, GZhP) from about 25% to 70% (compared with the technology of the gravity method of loading).

The stamp charging technology provides high-quality blast furnace coke with the use of up to 70% gas and low-caking coals in the coal blend. At the same time, the quality of the produced metallurgical coke is improved in comparison with the coke obtained by the traditional technology. Thus, the mechanical strength M25 was increased by an average of 2.2%, and index CSR by 5.0%, while the average parameters M10 and CRI, on the contrary, were decreased by 2.01 and 0.2% respectively. Also, coke obtained using the charge stamping method is characterized by lower values of ash content (0.3%) and total sulfur content (0.1%). The use of stamping technology also allows to reduce the cost of coal charge by $32.5/ton. Given the significant cost difference between the gravity and stamped coal charge, the payback period for the investment required for the reconstruction is less than 1 year.

Similar projects for transfer of operating coke batteries can be implemented on existing coke batteries to improve the quality indicators of produced coke and to significantly increase the economic performance of coke enterprises.

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