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THE CONTROL METHOD OF THE PRESSURE OF COAL BURSTING TO COMPOSE THE COAL CHARGE, AS A WAY OF EXTENDING THE WORKING SERVICE OF COKE OVENS

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Abstract

In the process of operating coke ovens, various loads influence a blast-furnace masonry. They lead to the gradual destruction of the masonry. It is generally accepted that the most destructive effect on the cladding of furnace chambers is the excessive pressure of bursting of coked coal charges. Dynamic loads from the falling stream of the charge during loading of furnaces are also quite dangerous. Due to such unbalanced, transverse pressure on the walls of the chambers coking, which starts when the batch is loaded and continues during the development of the burst pressure when coking, the deflection of the heating wall occurs, and it leads to its destruction. In the article, the method has been given for determining the bursting pressure of a coked coal load, which makes it possible to control this value, in order to ensure the safety of the masonry of oven walls of coke ovens.

***Keywords**: coal, coal charge; the process of coking; plastic mass; bursting pressure.*

1. Introduction

The modern technological process of blast-furnace production puts forward high requirements to the quality of coke, as it is the main costly component of the blast furnace charge. It is known that the quality of domain coke is influenced by two groups of factors. The first of them is related to the properties of the processed raw materials (coals and charge), and the second one is related to the coking mode and the post-furnace coke treatment (quenching, sorting, etc.). This fully applies to the mechanical "cold" strength of coke. Taking into account the fact that all over the world there are requirements for the "hot" strength of coke, determined by the indicators of CRI and CSR (18894 Coke - Determination of coke reactivity index (CRI) and coke strength after reaction (CSR)) by the method of Nippon Steel Corporation (Japan), and the quality of coke is determined mainly by the quality of the coal charge used in the coking feedstock. Coals are increasingly used to produce high-quality coke with CRI ≤ 30 % and CSR ≥ 70 % [1]. Studies have shown that these coals are characterized by high bursting pressure, which has a destructive effect on the masonry of the oven walls of coke oven batteries. In this regard, it is necessary to monitor the exponential pressure of the coal blends used for the coking process continuously. The extension the working service of coke ovens is the main task, and in this respect, the selection of coal concentrates with normal, i.e., a safe bursting pressure for the preparation of charge is urgently needed to ensure the integrity of the masonry walls of the furnaces. Since reliable methods for determining the magnitude of bursting pressure, at least in Ukraine, do not exist, we have set the goal of solving this problem ourselves.

Taking into account the availability of several technologies for the coke production in the production process – charge loading in the furnace in bulk and using the technology of ramming the charge, the method for determining the pressure of the batch is to be unified, i.e. allow determining in one apparatus the pressure of the expansion of both bulk and tamped charge (coals). In work [2], the authors give an overview of the known methods for determining the bursting pressure in experimental semi-industrial and laboratory furnaces. They make it possible to determine the bursting pressure of both bulk and tamped charges. However, charge loading in semi-industrial furnaces is 200–300 kg, and it results in a long duration of the determination, the unwieldiness of the instrumentation, the high cost of maintaining such an installation, and, consequently, the cost of one determination of the bursting pressure.

2. Experimental

To study the coal pressure and charge extrusion in the Ukrainian State Coal-Chemistry Institute, we have developed a universal laboratory setup, depicted in Fig. 1. It makes it possible to determine the value of the bursting pressure for the bulk and tamped method of loading coal (charge) [3-4]. Its design is protected by the patent of Ukraine [5], the results obtained allowed to develop, agree, approve in accordance with the established procedure and put into operation from 01.01.2018 DSTU 8724:2017 Coal and charge based on it. It is the method for determination of bursting pressure that occurs while coking.

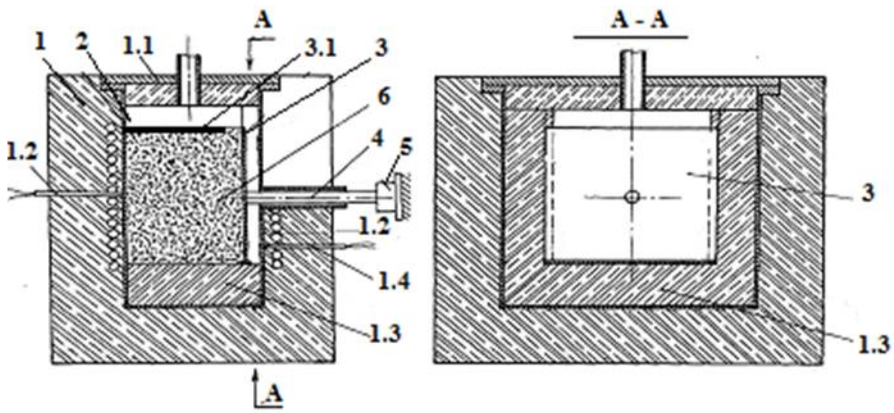

Fig.1. Unified furnace for determining the bursting pressure of tamped and bulk coal loading: 1 - electric furnace; 1.1 – an adiabatic cover with a gas bleeding branch pipe; 1.2 - electric heaters; 1.3 - thermal insulation; 1.4 - thermocouple; 2 - metal retort; 3 – steel plate l; 3.1 - steel perforated plate; 4 - quartz rod; 5 - pressure sensor; 6 - coal loading

The method consists in two-sided heating of the retort with coal loading at a given temperature, the sample parameters are given in Table 1, and the measurement of the bursting pressure by means of a piezoelectric pressure sensor in the range from 1 kPa to 70 kPa. The total time for determining the bursting pressure together with the preheating of the electric furnace to the set temperature is 4 hours.

Table 1. The parameters of the coal sample loaded into the retort

Loading	Loading weight, g	Mass fraction of particles by size <3 mm, %	Humidity of a coal sample (charge), %	Load density, g/cm^3
In bulk	600 ± 2	80 ± 3	10 ± 0,2	0,80 ± 0,01
Stamped	740 ± 2	90 ± 2	11 ± 0,2	1,13 ± 0,01

With two-sided heating of the coal loading, the peak of the bursting pressure (maximum) occurs at the moment of the merging of the plastic layers moving towards the heating walls from the axial plane. Such peaks are especially characteristic of coals or batch materials with high values of bursting pressure. With one-sided heating of the charge, there is no such peak; the pressure increases monotonically to the maximum value, and then begins to decrease.

3. Results and discussion

The conducted researches made it possible to simulate the process of coke formation, in such a manner that in the furnace chamber the coal charge is in different phases of thermal transformations, when the layer of initial coal coexists simultaneously (along the axial plane of the furnace), then in the direction of the heating wall, the plastic layer (the temperature range 330–510 °C) and a layer of semi-coke that passes into coke (Fig. 2).

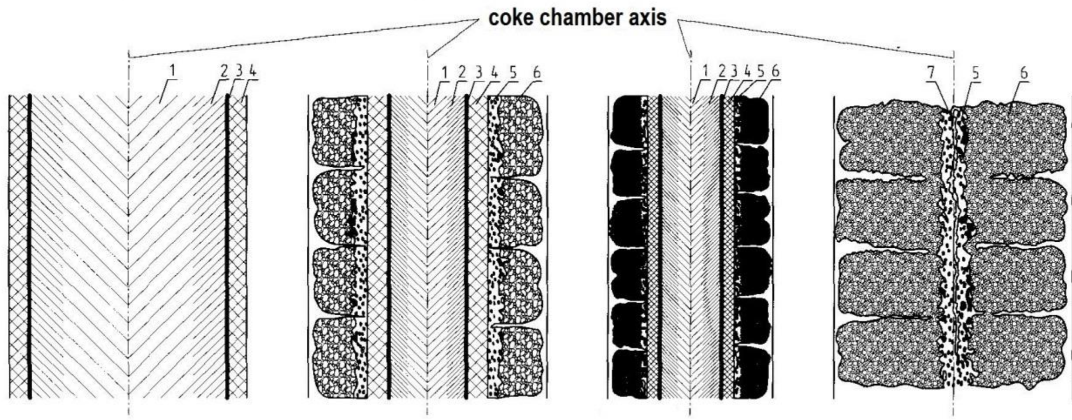

Fig. 2 shows a scheme of matter layers distribution in the load along the width of the coking chamber: 1 - moist coal (20°C); 2 - dry coal (200°C); 3 - coal in the softening state - swelling (330°C); 4 - hardening of the softened mass (510°C); 5 - semi-coke (600°C); 6 - coke (900°C); 7 - shrinkage seam along the axis of the chamber

The pressure of the pyrolysis gases formed in the plastic layer is transferred from one side to the initial coal charge, and on the other to the formed layer of coke, which adjoins the heating wall. The pressure exerted on the charge loaded with the bulk results in insignificant densification of the layer adjacent directly to the "cold" side of the plastic layer. In the case of a tamped charge compacted to high densities, this phenomenon does not occur, and all pressure of the vapor-gas products of the plastic layer is transferred through the coke layer to the heating wall.

The mechanism of development of the bursting pressure is the following: coal loading 2 at the boundary with the plastic layer 3 is initially a layer of slightly expanded grains, and it smoothly passes (toward the heating wall) into a layer of maximally expanded grains. Swelling of coal grains occurs as a result of the destruction of macromolecules of coal matter with the release of gaseous products. Acquisition of fluidity by the coal matter as a result of the destruction of rigid bonds between macromolecules and their fragments and accumulation of gaseous products in the coal grain leads to its swelling. As the temperature rises, the swelling of the grains increases, the porosity between them decreases, the grains crumble into each other. Sealing a layer of softened expanded grains from the "cold" side of the plastic layer creates a barrier that hinders the vapor-gaseous products from leaving the plastic layer. The plastic layer includes a layer of maximally expanded merged grains; this layer is formed as a result of rupture of the surface of the carbon grains and the release of the substance of coal that has passed into the liquid-mobile state. Later this layer passes into the foamed layer as a result of accumulation in it of a large quantity of vapor-gaseous products. As a result of the mass transfer of the coal substance from this layer towards the heating wall, a compacted layer of plastic mass is formed which, with a further increase in temperature, is converted into semi-coke 5, and then to coke 6, which is a solid porous substance. The barrier to the release of continuously generated gases from the plastic layer on the "hot" side is a compacted semi-hardened layer of plastic mass, characterized by low porosity. Semi-coke and coke as a result of further temperature transformations acquire a sufficiently high porosity (40–45 %), notably about 80 % of these pores being communicating, and therefore sufficiently gas permeable.

The strength of semi-coke and coke is high enough for them to transfer pressure from the plastic layer to the heating wall. Thus, on the one hand, a layer of softened swollen fused carbon grain prevents the free release of vapor-gaseous products from the plastic layer, and on the other hand, it is a layer of the primary semi-coke. The stronger and less gas-permeable these layers, the higher the gas pressure developed in the plastic layer, which is transferred through the semi-coke and coke to the heating wall. It should be noted that the rate of gases formation in the plastic layer is not a determining factor in the development of a large bursting pressure. This is confirmed, for example, by the fact that coals with the release of volatile substances 40 % develop a bursting pressure of the order of 2.5–4.0 kPa, while coals with V^{daf} =25 % – up to 20 kPa. The main condition is the gas tightness of the barriers on the "cold" and "hot" side of the plastic layer. Thus, the development of a particular magnitude of the bursting pressure is associated with the structure of the plastic layer, the properties of the plastic mass and the character of the coke formation.

After the test has been completed, the heating of the furnace is turned off, and the retort is left for another three hours for the thermal aging of the coke. After that, the retort already cooled to ~ 300°C, is removed from the furnace and left in the air for final cooling. Thus, "dry" quenching of coke is provided. If necessary, the resulting coke is tested for mechanical strength in a special drum and examined by other methods.

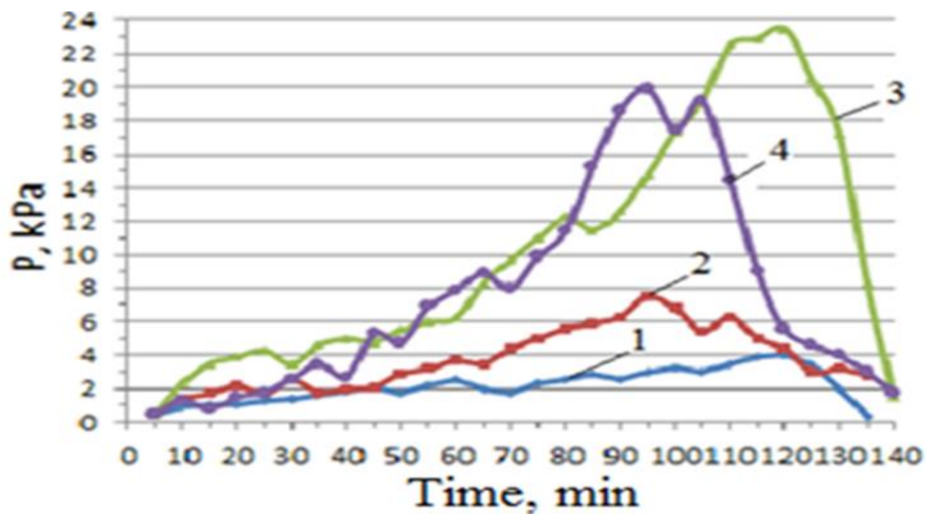

Fig. 3. The development dynamics of the pressure of coal extrusion in the coking process: 1 – Mine "Raspadskaya" (Russia); 2 – "Carter Rogue" (USA); 3 – LOV VOLATILE CC (USA); 4 – "Pocahontas" (USA)

Table 2. Characteristics of bituminous coals (B)

Sample (grade)	Supplier	Technical analysis, %			Petrographic composition, %						Plastic layer characteristics, mm	
		A^d	S^d_t	V^{daf}	R_0	V_t	S_v	I	L	Σ FK	x	y
B-1	Mine «Raspadskaya» (Russia)	8,6	0,47	37,3	0,83	88	1	8	3	9	40	16
B-2	«Karter Roag» (USA)	8.5	0.69	31.8	1.02	92	0	7	1	7	29	17
B-3	«LOV VOLATILE CC» (USA)	9,3	0,82	19,0	1,40	74	0	26	0	26	27	14
B-4	«Pocahontas» (USA)	8,9	0,94	18,0	1,54	69	2	29	0	31	10	10

In industrial coking chambers, the maximum burst pressure as a result of the combined effect of processes occurring in different loading layers is reached at the end of the second hour after charging the batch at the oven sole. In calculating the strength of heating sections, the maximum allowable bursting pressure is assumed to be 7 kPa [6]. The obtained results on a unified laboratory installation indicate that the coals develop a much higher pressure – up to 15–20 kPa, and therefore coking of the charge with their participation leads to a bursting pressure exceeding the permissible level. For example, Fig. 3 shows the dynamics of the bursting pressure in the process of coking coal during bulk loading, i.e., at an apparent density of 800 kg/m^3. The characteristics of coal concentrates are given in Table. 2.

4. Conclusion

The obtained practical results of the pressure of the coal extrusion allowed to conclude that the weakly baking coal of grade B1 is characterized by small values of the expansion pressure (0.9÷4.0 kPa), coal of grade B2 develop the average burst pressure (4.0÷8.0 kPa), and grades B3, B4 is the most open (6.0÷24.0 kPa). Moreover, due to the fact that many differently directed factors affect the expansion pressure, this quantity is not additive. Therefore, the only reliable way to estimate the bursting pressure is to determine it experimentally, to select, on the basis of the results obtained, the charge compositions that provide safe pressure values, and to use the results of the studies in the strength calculations of the heating sections.

Symbols

A^d	*ash content of coal in the dry state, %;*
V^{daf}	*volatile matter in the dry ash-free state, %;*
S_t^d	*sulphur of coal in the dry state, %;*
R_0	*mean vitrinite reflection coefficient, %;*
V_t	*vitrinite, %;*
S_v	*semivitrinite, %;*
I	*inertinite, %;*
L	*liptinite, %;*
ΣFC	*sum of fusinized components, %;*
x	*plastometric shrinkage, mm;*
y	*thickness of the plastic layer, mm;*
DSTU	*Ukrainian State Standard*

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