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EFFECT OF EXPANSION PRESSURE OF THE COAL BLEND IN THE PROCESS OF COKING ON THE REFRACTORY MASONRY OF COKE OVENS

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Abstract

The studies conducted on one of the coke batteries showed that as the pressure of the charge spreads, the amount of throughput of raw coke gas in the heating system of the oven increases, which indirectly confirms the relationship between the pressure of the load and the deflection of the heating wall.

Keywords*: Coal blend; Coke oven; Coking; Distension pressure; Heating wall; Raw coke oven gas; Leakage.*

1. Introduction

The total service life and efficiency of coke oven batteries depend on the preservation of the masonry walls of the chambers. There are a lot of examples when coke oven batteries have worked and continue to work without significant performance degradation (more than 30 years). But there are other examples when, due to the poor technical condition of the refractory masonry of the furnace chambers, after 15 years of operation, it was necessary to stop the batteries for rebuilding. It is difficult to explain and highlight the main factors affecting such a range of battery life. This article examines the effect of the pressure of the expansion of the coal charge in the process of coking on the refractory masonry of coke ovens.

During the operation of coke ovens, various loads act on the refractory masonry, leading to its gradual destruction. It is generally accepted that the most destructive effect on the masonry of the furnace chambers is exerted by the excessive pressure of the coking charge that prevents the coke cake from moving away from the heating walls of the coking chamber in time, which creates conditions for the increased amperage of the furnace output. In the presence of serious damage to the masonry, the increased pressure of the expansion of the charge leads to the drilling of the furnaces on delivery. Such damages include: chips, "under-cuts", shells of various depths, dips, individual bricks or groups of bricks protruding into the coking chamber, deformation of the walls (bulge or concavity), narrowing of the chambers on the coke side, narrowing of the chambers up, slagging, worn down the bottom bricks and others. Excessive, uneven in thickness, deposits of wall "graphite" also create mechanical resistances when giving out a coke cake, thereby contributing to slow running or drilling. As practice shows, a tight stroke or drilling of a coke cake is repeated, as a rule, on the same ovens, which are the most damaged [1-3]. Dynamic loads from a falling charge flow when loading ovens are also quite dangerous [4]. As a result of this unbalanced lateral pressure on the walls of the coking chambers, starting even when the charge is loaded and continuing in the process of development of the bursting pressure during its coking, a deflection of the heating pier occurs.

Cyclically repeated deflections, and then alignment of the pier, lead to its hidden destruction. Using the method of measuring deflections with the help of Karl Stiel laser deflectometer with a coking chamber height of 6 m when loading a wet charge, it was shown that the amount of deflection in the middle of the pier length is 4.8 mm. When the furnace, bordering an empty oven, was loaded, for the first 15 minutes the pier changed by 4.7 mm, and by the end of the coking period changed by 10.2 mm [5].

Similar measurements were carried out by Japanese researchers [6]. Measurements on furnaces with a height of 6 m and a width of 0.43 m were carried out on a section of furnaces after 32 years of service without repair and on a section where the laying of five furnaces was completely shifted after 25.3 years of service. At the same time, gas pressure was measured using steel capillary tubes placed in a wet coal charge. The end of the tube was at a level of 3.3 m from the hearth of the furnace and at a distance of 2 m from the lining of the door. The obtained value of the maximum gas pressure was taken by the authors as the expansion pressure of the charge. A graph of the displacement of the heating wall from the maximum gas pressure is constructed. With a gas pressure of 7 kPa, the displacement of the wall of the shifted (new) chamber was 1 mm, and that of the old chamber was 4.5 mm.

Thus, the more worn out the coke ovens and the greater the expansion pressure of the coking charge are, the greater the displacement (deflection) of the heating walls, the higher their gas permeability must be, and the greater washout of the raw coke gas will flow into the heating wall.

2. Experimental

The determination of the volume of the washout of the raw coke oven gas was carried out on the coke oven battery of PVR system with paired vertical channels and recycling, which was put into operation in 1957, after 27 years of operation the transfer was performed. The height of the coking chamber is 4300 mm; the width of coking chambers is 410 mm; the chamber length is 13980 mm; the number of gas collectors is 2 pieces; the useful volume of the coking chamber is 21.6 m^3; the number of stoves in the battery is 61 pcs. The design capacity of coke 6 % humidity is 455 thousand tons/year.

For a long time of operation, the battery is worn, the coke oven chambers have undergone significant deformation, many coking chambers are narrowed from the coke side, and therefore, the mechanical masks were used in the narrow places, which significantly reduced the thickness of the heating walls and, consequently, the strength of the heating pier. There was a narrowing of the chambers on the coke side, and, on this side, their width is 400-385 mm. In addition, there was a narrowing of the cameras up above the average of another 20 mm. If the height of the underwater space was observed according to the rules of technical operation (250-350 mm), many furnaces had an increased amperage (up to 500 A) and drilling of furnaces. In this regard, in all furnaces, the charge loading level is reduced by 100 mm. In addition, some furnaces were loaded with a slope on the coke side of 0.7-1.0 m. On a number of furnaces, for which the maximum output rate is observed, the charge set in the "third" bunker of the coal-loading car is halved. The working amperage of the furnaces is up to 250 A.

The determination of the washout volume characterizing the tightness of the masonry was carried out according to the oxygen balance in the combustion products when the heating gas is supplied to the pier and when it is turned off. When the supply of heating gas to the wall is turned off, combustion products in it are formed only due to the burning of raw coke oven gas leaked from the coking chamber. In this case, the air in the pier flows in the same way as when the heating gas is supplied. The analysis of the composition of combustion products was carried out using an electric gas analyzer TESTO-350.

After analyzing the combustion products formed in the pier when the heating (coke) gas is supplied, the test pier was disconnected from the heating. After 30 seconds, when the combustion products from the most distant verticals in the middle part of the pier passed through the gas-air valve (GAV), the measurement of the composition of the combustion products began. The obtained data was used to calculate the value of throughput of raw coke oven gas according to the method [7]. This technique takes into account the effect of coal tar and raw benzene in raw coke oven gas on the value of the washout. The washout are decided to determine the 2/3 period of coking.

3. Results and discussion

When conducting research, the single blend loading into the furnace (G_b) in terms of dry weight was 15.6 tons, the yield of coke oven gas (V_g) from one ton of dry blend was 339 m^3. The pressure of the expansion blend at the first stage of research was 5.1 kPa, at the subsequent stage is 5.8; 6.7; 7.2 and 7.8 kPa. The petrographic characteristics of coal concentrates participating in the blend are presented in Table 1. The vintage composition of the coal blend is given in Table 2. Table 3 shows the technological properties of the coal blend.

Table 1. Petrographic characteristic of bituminous coals (B)

Type Coal	Petrographic composition (without mineral impurities), %					Medium random indicator of vitrinite reflection, %
	V_t	S_v	I	L	ΣFK	R_o
B1	80	0	19	1	19	0.67
B2	82	0	16	2	16	1.00
B3	89	1	9	1	10	1.19
B4	78	1	21	0	22	1.54

Table 2. Grade composition of coal blends

Type coal	Blend options, %				
	1	2	3	4	5
B1	25	20	25	25	15
B2	30	30	30	25	25
B3	30	50	30	40	60
B4	15	–	15	10	–
Total	100	100	100	100	100

Table 3. Technological properties of coal blend

Blend option	Technical analysis, %				Plastometric indicators, mm		Basicity index	Expansion pressure, kPa
	W^a	A^d	S^d_t	V^{daf}	x	y	I_b	P
1	1.2	9.4	0.72	28.7	36	16	1.75	5.1
2	0.6	8.8	0.76	28.8	28	15	2.30	5.8
3	1.1	8.9	0.81	29.4	26	15	2.18	6.7
4	1.0	7.9	0.78	29.8	25	16	2.14	7.2
5	0.8	8.7	0.78	29.0	22	16	2.28	7.8

The indicators of pressure expansion were determined on a laboratory unified installation of SE "UKHIN" [8].

The theoretical consumption of oxygen for the combustion of coke oven gas (with α=1) of the above composition was calculated by stoichiometric calculation of the combustion of gas components:

$CH_4 + 2O_2 = CO_2 + 2H_2O$ (1)

$2CO + O_2 = 2CO_2$ (2)

$2H_2 + O_2 = 2H_2O$ (3)

$C_2H_4 + 3O_2 = 2CO_2 + 2H_2O$ (4)

In the calculations of combustion processes, to simplify, it was assumed that heavy hydrocarbons (C_mH_n) consist of ethylene C_2H_4. The calculation data for the combustion of coke oven gas is given in Table 4.

Table 4. The calculation of the conditions of combustion of coke oven gas (at $\alpha = 1$)

Gas component	Content in gas, %	O_2 required for combustion, m^3	Converted to combustion products, m^3
CH_4	23.3	46.6	–
H_2	58.6	29.3	–
CO_2	3.0	–	3.0
CO	7.6	3.8	–
C_mH_n	3.0	9.0	–
O_2	0.8	0.8	–
N_2	3.7	–	3.7
Total	100	87.9	6.7

The theoretical consumption of oxygen (O_{2T}) when burning coke oven gas is 0.879 m^3/m^3 gas. The consumption of heating gas for heating the walls of the machine side of the battery was 5100 m^3/h, the coefficient of excess air (α) is 1.52.

The amount of oxygen in the air needed to burn the heating gas that flows into one half (on the machine side) of one pier is calculated by the following formula:

$$O_2 = \frac{V_g \times \alpha \times O_{2T}}{N}, \text{ m}^3/\text{h} \quad (5)$$

where: V_g – heating gas consumption on the engine side of the pier, m^3/h; α – the coefficient of excess air; O_{2T} – theoretical consumption of oxygen required for burning coke oven gas of this composition, m^3/m^3; N – the number of washout in the battery.

$$O_2 = \frac{3750 \times 1.52 \times 0.879}{62} = 80.8 \text{ m}^3/\text{h} \quad (6)$$

The O_{2B} (%) oxygen content in the combustion products with the heating gas supply turned off, as measured by the gas analyzer in GAV, was 19.20 with pressure of 5.1 kPa; 19.15 – at 5.8 kPa; 18.78 – at 6.7 kPa; 18.30 – at 7.2 kPa and 17.0 – at 7.8 kPa. That is, the higher the pressure of the blend is, the less oxygen in the combustion products is. The amount of oxygen required to burn the raw coke oven gas of the downpipes, half (on the machine side), of the pier was calculated by the formula:

$$O_{2B} = \frac{O_2(21 - O_{2cp})}{0.21 \times 100}, \text{ m}^3/\text{h} \quad (7)$$

where O_2 = 80.8 m^3/h, (see equation 6); O_{2cp} – oxygen content in raw gas combustion products, %; 21 – oxygen content in the air, %.

Under the expansion pressure of the mixture, equal to 5.1 kPa, the amount of oxygen is:

$$O_{2B} = \frac{100(21.00 - 19.20)}{0.21 \times 100} = 6.9 \text{ m}^3/\text{h} \quad (8)$$

The volume of the washouts (W) is determined by the formula:

$$W = \frac{O_{2B}}{O_{2T} \times 1.67}, \text{ m}^3/\text{h} \quad (9)$$

where 1.67 – coefficient taking into account the effect of coal tar and raw benzene on the value of the raw coke gas penetration into the heating system of the furnace.

Then the volume of the washouts of the raw coke oven gas in the heating system at the expansion pressure of the mixture of 5.1 kPa is:

$$W = \frac{6{,}9}{0.879 \times 1.67} = 4.7 \text{ m}^3/\text{h} \quad (10)$$

The share of the washouts as a percentage of the total gas released from the blend during the coking process is:

$$\pi = \frac{100 \times W \times CP \times 2}{Gb \times Vg}, \text{ \%} \quad (11),$$

where W – the volume of gas washout, m^3/h; CP – coking period, h; 2 – coefficient taking into account the formation of volatile products of coking (approximately in equal shares on the machine and coke side of the coking chamber); G_b – single blend loading into the furnace; V_g – heating gas consumption on the engine side of the pier, m^3/h.

Then, under the pressure of the expansion of the blend of 5.8 kPa:

$$\pi = \frac{100 \times 4.7 \times 19.0 \times 2}{15.6 \times 339} = 3.4 \text{ \%} \quad (12)$$

The value of the washout is 3.4 % for a coke oven battery of the specified age is very satisfactory. However, it should be noted that this value was obtained with a relatively low pressure expansion of the mixture. With an increase in the pressure of the expansion of the blend to 6.7 kPa, the increase in the magnitude of the washout was 23.5 % relatively. And when using the blend with a pressure of expansion of 7.8 kPa, the magnitude of the washout was 7.6 %, i.e. more than doubled. The results are presented in Fig. 1 as a graph.

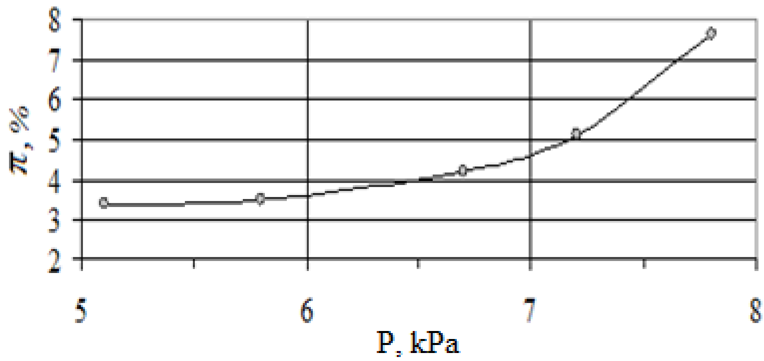

Fig. 1. The dependence of the washout value of raw coke oven gas (π) into the heating system on the expansion pressure (P) of the blend

The shape of the obtained curve of the dependence of the amount of discharge on the pressure of the blend of the blend may indicate that the heating walls of the furnaces on the battery are significantly worn and their displacement during the process of loading the chambers and coking increases sharply with increasing the expansion pressure of the blend. Therefore, for such furnaces, blend with the lowest burst pressure is recommended (taking into account the production of conditioned blast furnace coke).

Theoretical and practical interest is the study of the dynamics of the raw coke gas washout from the beginning of the furnace loading. The studies were carried out on the same furnace as in batches with various expansion pressures; the analysis of combustion products was carried out in gas-air valves of the heating walls, every hour. The pressure of the blend of the mixture was 6.7 kPa. The results are presented in Fig. 2

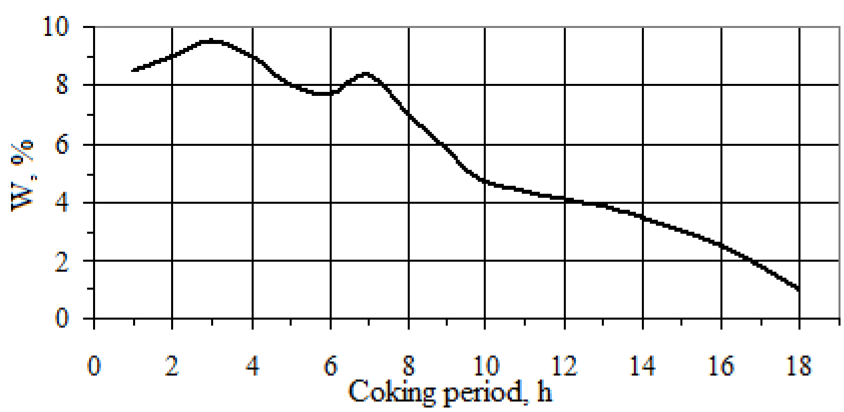

Fig. 2. The dynamics of the washout (W) of the raw coke gas

From the figure it follows that from the first to the third hour the washouts increase and reach a maximum. Their high values up to the first hour of the coking period, when the pressure of the mixture is still at the beginning of development, can be explained by the influence of the thrusting forces created by the flow of the loading blend. According to the work [4], when loading a wet mixture in the first minutes, these efforts (pressure on the walls) reach 12 kPa, and then quickly decrease and stabilize at 3 kPa. The maximum of the downfalls is observed at the third hour of the coking period, which coincides with the maximum pressure of the expansion for wet charges. Then there is a decrease in the drainage, which, apparently, is associated with the beginning of the alignment of the deflection of the pier. By this time, a rather thick layer of semi-coke–coke had already formed, which was accompanied by shrinkage phenomena, however, a gap between the coke and the heating wall of the coking chamber was not formed yet. The surge in the increase in the washout at the seventh hour is obviously associated with a surge in the pressure of the burst when the plastic layers merge along the axis of the coking chamber. After this, there is a sharp decline in the value of the washout. This is consistent with the time of formation of a hollow seam along the axis of the coke cake and its departure from the heating walls, as a result of which the resistance to returning the pier to its original position decreases and then disappears completely. The arithmetic average value of the washout was 5.4 %, whereas by 2/3 of the coking period it was 4.1 %, which is significantly lower than the average value.

4. Conclusions

The largest volume of washout of the raw coke gas into the heating system occurs in the first hours of the coking period. By the end of the coking period, there is almost no washout. The nature of the dynamics of the washout is close to the dynamics of pressure expansion.

The magnitude of the washout with increasing pressure expansion of the coked load increases, which indirectly confirms the connection of the washout value to the deflection of the heating walls.

The average value of the washout takes place at about half the period of coking; it is about 30 % higher than the value of the washout, determined by 2/3 of the coking period.

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;*
I_b	*basicity index*
P	*expansion pressure, kPa*
α	*coefficient of excess air*

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