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Movement of Coke in the Dry Coke Quenching Plant During its Unloading

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Abstract

The article presents experimental data on the nature of coke movement in the DRY COKE QUENCHING PLANT (DCQP) chamber during its unloading. It is shown that when the coke is unloaded, zones of accelerated coke descent and stagnant zones appear. The number of zones of accelerated descent of the quenched coke increases in proportion to the number of structural reinforcing beams. The dimensions of these zones are the larger, the smaller the surface of the blow head. A larger number of zones of accelerated descent create a condition for a more uniform descent of coke throughout the entire volume of the DCQP chamber. Also, the manifestation of the action of zones of accelerated descent begins the earlier, the smaller the surface of the blow head. This required a constructive way to achieve the uniformity of the descent of coke to improve the technological characteristics of the work of the DCQP.

Keywords: *Model DCQP; Movement of coke in the chamber; Zone of accelerated descent of coke.*

1. Introduction

Recently, there have been many publications devoted to improving the quality of produced blast-furnace coke [1-5]. The question of the nature of the movement of coke inside the DCQP chamber in the domestic coke chemical science is rather poorly covered. An analysis of early publications on the operation of coke dry quenching plants revealed a number of works [6-14] that deal with general design issues and operation features of domestic and foreign coke dry quenching plants. And only some works [15-17] deal with the issue of coke movement as a bulk material in the volume of the DCQP chamber. The fact that this area of the process of dry coke quenching has not been studied indicates the relevance of this issue and is explained by the impossibility of conducting research on a directly operating industrial DCQP. Such studies can be performed using either mathematical or laboratory modeling.

2. Methodology

The study of the patterns of coke movement in the volume of the fire extinguishing chamber included:

- determination of the coke surface profile during unloading (emptying) through the unloading device;
- determination of the position of the zones of accelerated coke descent and, accordingly, stagnant zones during the movement of coke in the DCQP with different design of the coolant supply to the blower head - one or two beam design, as well as various forms of the DCQP blower heads.
- determination of ratios in the speeds of coke movement inside the DCQP chamber regarding zones of accelerated descent and stagnant zones of coke.

The diversity of the conducted studies was due to the fact that the technical and economic indicators of the work of the DCQP are closely interconnected with the uniformity of the processes of movement of the heat-carrier gas and coke, when it is cooled in the quenching chamber.

The research methodology [18-19] was carried out according to the following scheme: model coke was loaded into a model coke car, simulating the stacking of coke when unloading it from the coking chamber. Then the coke from the coke car was loaded through the loading funnel into the DCQP model until the level of the forechamber was filled with coke. Then, through the unloader, it was unloaded in equal portions (approximately 9% of the volume) from the DCQP, after which the analysis of these coke surface profiles was carried out after each emptying of the DCQP. Fixed breaks in the surface of the unloaded coke were considered to be either zones of accelerated descent of coke (pit) or stagnant zones (mountain).

In a single-beam DCQP, the surface profile was set for the points:

- above the blast beam along the plane dividing the side sectors in half (solid line);
- along a perpendicular plane dividing in half the sectors simulating the coke and boiler sides (dashed line).

Schematically, the procedure for conducting research on the fracture of the surface of the unloaded coke is shown below in Figure 1. In a two-beam DCQP, surface profiles were recorded in planes dividing the sectors in half. Data on the characteristics of the descent of coke are presented in Figures 2-4.

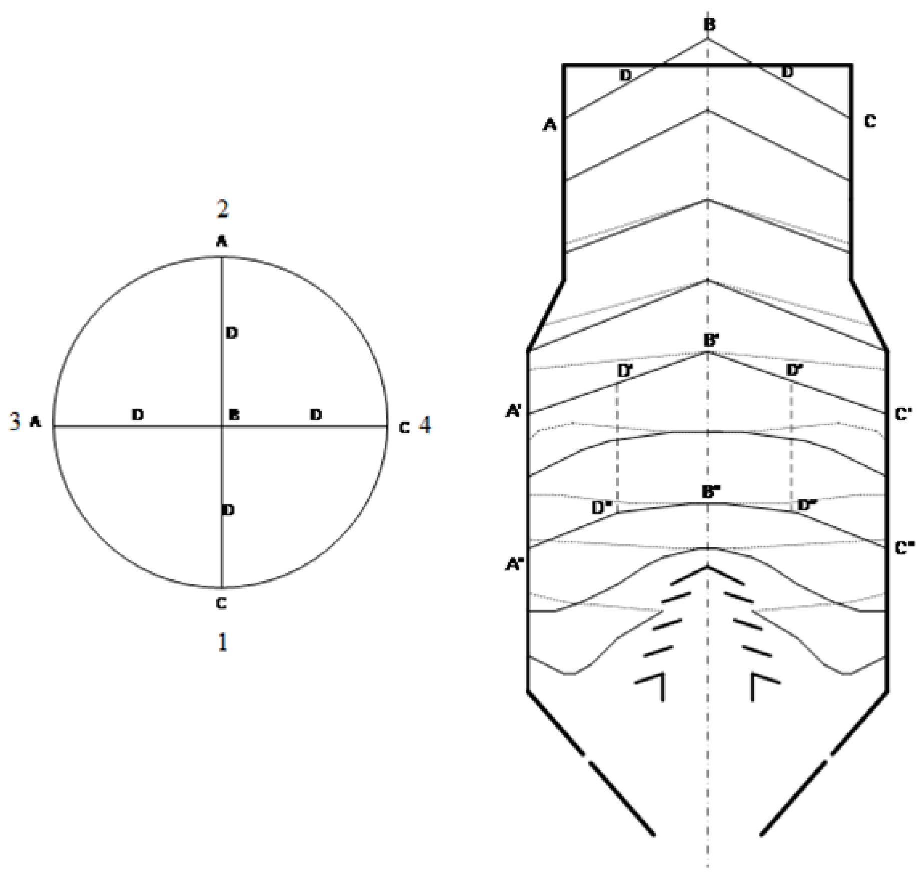

Fig. 1. Schematically, the procedure for conducting research on the fracture of the coke surface in the DCQP model

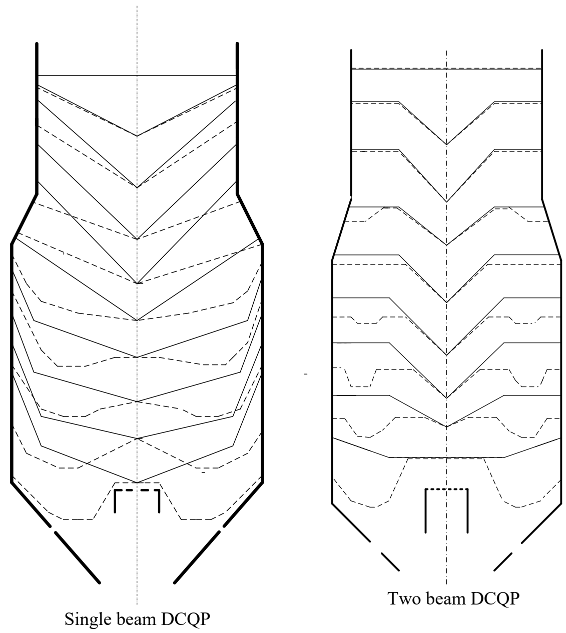

Fig. 2. The nature of coke surface profiles during batch unloading of one- and two-beam DCQP with a single-level blower head

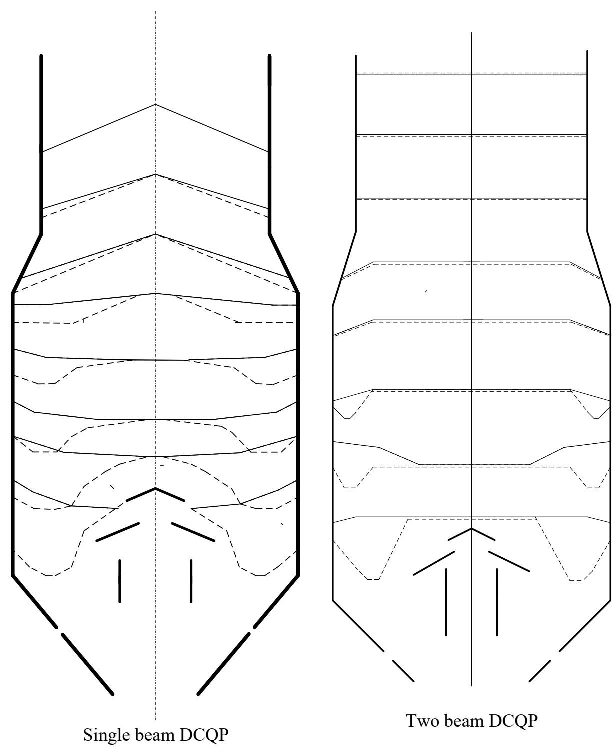

Fig. 3. The nature of the coke surface profiles during batch unloading of a one- and two-beam DCQP with a two-level blower head

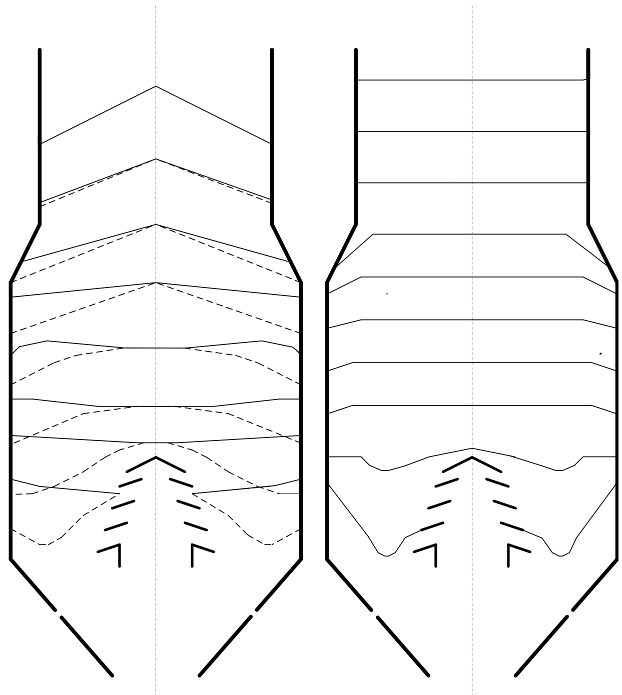

Fig. 4. The nature of the coke surface profiles during batch unloading of a one- and two-beam DCQP with a five-level blower head

Also, the movement of coke was simulated when loading to the center of the car (in order to reduce coke segregation in the car), loading coke using a divider in the loading area and a loading device of a confuser-diffuser type, as well as blow heads of 5 and 2 levels and "flat" (single-level) blow head.

3. Results and discussion

In numerical terms, the change in the rate of coke descent in the fire extinguishing chamber of the DCQP, depending on the design of the blower head and the difference in the supply of coolant gas, is presented in Tables 1-6.

Table 1. Analysis of changes in the profile of the coke charge during its unloading from the model of a dry coke quenching plant with a single-level blower head design and a two-beam coolant supply (Figure 2, two-beam DCQP)

Unloading No.	Percentage of change in coke load volume from the initial charge at control points				
	A	D	B	D	C
Analyzed unloading sector 1-2					
1	0.0899	0.1134	0.1911	0.1134	0.0899
2	0.1259	0.1271	0.1502	0.1271	0.1259
3	0.1583	0.1409	0.1092	0.1409	0.1583
4	0.1295	0.1306	0.1468	0.1306	0.1295
5	0.1151	0.1340	0.1365	0.1340	0.1151
6	0.1223	0.1100	0.1092	0.1100	0.1223
7	0.1403	0.1168	0.0751	0.1168	0.1403
8	0.1187	0.1271	0.0819	0.1271	0.1187

Unloading No.	Percentage of change in coke load volume from the initial charge at control points				
	A	D	B	D	C
Analyzed unloading sector 3-4					
1	0.0844	0.1125	0.1911	0.1125	0.0844
2	0.1136	0.1125	0.1502	0.1125	0.1136
3	0.1753	0.1344	0.1092	0.1344	0.1753
4	0.1039	0.1188	0.1468	0.1188	0.1039
5	0.1299	0.1250	0.1365	0.1250	0.1299
6	0.1234	0.1125	0.1092	0.1125	0.1234
7	0.1234	0.1125	0.0751	0.1125	0.1234
8	0.1461	0.1719	0.0819	0.1719	0.1461

Table 2. Analysis of changes in the profile of the coke charge during its unloading from the model of a dry coke quenching plant with a single-level blower head design and a single-beam coolant supply (Figure 2, single-beam DCQP)

Unloading No.	Percentage of change in coke load volume from the initial charge at control points				
	A	D	B	D	C
Analyzed unloading sector 1-2					
1	0.0705	0.0760	0.1486	0.0760	0.0705
2	0.1245	0.0798	0.1268	0.0798	0.1245
3	0.1037	0.1179	0.1268	0.1179	0.1037
4	0.1037	0.1065	0.1087	0.1065	0.1037
5	0.1618	0.1483	0.0906	0.1483	0.1618
6	0.0954	0.1445	0.0906	0.1445	0.0954
7	0.1245	0.1293	0.1087	0.1293	0.1245
8	0.1245	0.1027	0.0906	0.1027	0.1245
9	0.0913	0.0951	0.1087	0.0951	0.0913
Analyzed unloading sector 3-4					
1	0.0444	0.0686	0.1486	0.0686	0.0444
2	0.0778	0.0915	0.1268	0.0915	0.0778
3	0.1926	0.1536	0.1268	0.1536	0.1926
4	0.0741	0.0915	0.1087	0.0915	0.0741
5	0.0630	0.1209	0.0906	0.1209	0.0630
6	0.0926	0.1176	0.0906	0.1176	0.0926
7	0.1852	0.1111	0.1087	0.1111	0.1852
8	0.1481	0.1307	0.0906	0.1307	0.1481
9	0.1222	0.1144	0.1087	0.1144	0.1222

Table 3. Analysis of changes in the profile of the coke charge during its unloading from the dry coke quenching unit DCQP with the design of a two-level blower head with a two-beam design of the coolant supply (Figure 3 two-beam DCQP)

Unloading No.	Percentage of change in coke load volume from the initial charge at control points				
	A	D	B	D	C
Analyzed unloading sector 1-2					
1	0.1304	0.1338	0.1333	0.1338	0.1304
2	0.1413	0.1450	0.1444	0.1450	0.1413
3	0.1739	0.1413	0.1407	0.1413	0.1739
4	0.1268	0.1338	0.1333	0.1338	0.1268
5	0.1630	0.1599	0.1593	0.1599	0.1630
6	0.0906	0.1599	0.1667	0.1599	0.0906
7	0.1739	0.1264	0.1222	0.1264	0.1739
Analyzed unloading sector 3-4					
1	0.1306	0.1271	0.1402	0.1271	0.1306
2	0.1306	0.1271	0.1402	0.1271	0.1306
3	0.1649	0.1271	0.1402	0.1271	0.1649
4	0.1203	0.1204	0.1328	0.1204	0.1203
5	0.1649	0.1438	0.1587	0.1438	0.1649
6	0.1340	0.1538	0.1661	0.1538	0.1340
7	0.1546	0.2007	0.1218	0.2007	0.1546

Table 4. Analysis of changes in the profile of the coke charge when it is unloaded from the dry coke quenching unit DCQP with the design of a two-level blower head with a single-beam coolant supply structure (Figure 3, single-beam DCQP)

Unloading No.	Percentage of change in coke load volume from the initial charge at control points				
	A	D	B	D	C
Analyzed unloading sector 1-2					
1	0.1823	0.1674	0.1810	0.1674	0.1823
2	0.2031	0.1628	0.1538	0.1628	0.2031
3	0.0885	0.1209	0.1538	0.1209	0.0885
4	0.1354	0.1581	0.1674	0.1581	0.1354
5	0.1563	0.1581	0.1584	0.1581	0.1563
6	0.1042	0.0977	0.0950	0.0977	0.1042
7	0.1302	0.1349	0.0905	0.1349	0.1302
Analyzed unloading sector 3-4					
1	0.1652	0.1612	0.1810	0.1612	0.1652
2	0.1870	0.1488	0.1538	0.1488	0.1870
3	0.0826	0.1240	0.1538	0.1240	0.0826
4	0.1304	0.1198	0.1674	0.1198	0.1304
5	0.1522	0.1446	0.1584	0.1446	0.1522
6	0.1522	0.1364	0.0950	0.1364	0.1522
7	0.1304	0.1653	0.0905	0.1653	0.1304

Table 5. Analysis of changes in the profile of the coke charge when it is unloaded from the dry coke quenching unit DCQP with a five-level blower head design with a two-beam coolant supply structure (Figure 4, two-beam DCQP)

Unloading No.	Percentage of change in coke load volume from the initial charge at control points				
	A	D	B	D	C
Analyzed unloading sector 1-2					
1	0.1145	0.0993	0.1167	0.0993	0.1145
2	0.1145	0.0993	0.1167	0.0993	0.1145
3	0.1832	0.0993	0.1167	0.0993	0.1832
4	0.0649	0.0828	0.0973	0.0828	0.0649
5	0.0763	0.0828	0.0973	0.0828	0.0763
6	0.0954	0.0828	0.0973	0.0828	0.0954
7	0.0954	0.0828	0.0973	0.0828	0.0954
8	0.0954	0.0828	0.0973	0.0828	0.0954
9	0.0954	0.1225	0.0973	0.1225	0.0954
10	0.0649	0.1656	0.0661	0.1656	0.0649
Analyzed unloading sector 3-4					
1	0.1145	0.0993	0.1167	0.0993	0.1145
2	0.1145	0.0993	0.1167	0.0993	0.1145
3	0.1832	0.0993	0.1167	0.0993	0.1832
4	0.0649	0.0828	0.0973	0.0828	0.0649
5	0.0763	0.0828	0.0973	0.0828	0.0763
6	0.0954	0.0828	0.0973	0.0828	0.0954
7	0.0954	0.0828	0.0973	0.0828	0.0954
8	0.0954	0.0828	0.0973	0.0828	0.0954
9	0.0954	0.1225	0.0973	0.1225	0.0954
10	0.0649	0.1656	0.0661	0.1656	0.0649

Table 6. Analysis of changes in the profile of the coke charge during its unloading from the dry coke quenching unit DCQP with a five-level blower head design with a single-beam coolant supply structure (Figure 4, single-beam DCQP)

Unloading No.	Percentage of change in coke load volume from the initial charge at control points				
	A	D	B	D	C
Analyzed unloading sector 1-2					
1	0.1777	0.1759	0.1807	0.1759	0.1777
2	0.1777	0.1620	0.1597	0.1620	0.1777
3	0.1015	0.1204	0.1429	0.1204	0.1015
4	0.1726	0.1528	0.1597	0.1528	0.1726
5	0.1320	0.1620	0.1471	0.1620	0.1320
6	0.1066	0.0926	0.0840	0.0926	0.1066
7	0.1320	0.1343	0.1261	0.1343	0.1320
Analyzed unloading sector 3-4					
1	0.1581	0.1667	0.1807	0.1667	0.1581
2	0.1880	0.1667	0.1597	0.1667	0.1880
3	0.1282	0.1292	0.1429	0.1292	0.1282
4	0.1282	0.1125	0.1597	0.1125	0.1282
5	0.1453	0.1500	0.1471	0.1500	0.1453
6	0.1282	0.1458	0.0840	0.1458	0.1282
7	0.1239	0.1292	0.1261	0.1292	0.1239

In these tables, the fracture profiles of the surface of the coke grist after each emptying of the DCQP through the unloader are expressed in terms of unit fractions of the total unloaded coke from the DCQP model.

The analysis of the obtained results made it possible to reveal general patterns. For a single-beam DCQP with a five- and one-level blow head, the surface profiles are similar. In each experiment, as it is emptied, a lower location of the profiles in the sectors of the coke and boiler sides (dashed line) is recorded compared to the side sectors (solid line), which indicates the presence of two zones of accelerated coke descent. These zones are observed in the sectors of the boiler and coke sides approximately in the middle between the wall of the quenching chamber and the edge of the blow head.

The analysis of Tables 1-6 shows that the maximum change in the speed of coke movement for the DCQP with different design of the coolant supply to the blower head (single-beam design - option 1, double-beam design - option 2) is:
- DCQP with a single-level blower head: option 1 - 7.0%; option 2 - 4.3%;
- DCQP with a two-level blower head: option 1 - 6.5%; option 2 - 3.0%;
- DCQP with a five-level blower head: option 1 - 10.6%; option 2 - 2.8%;

Analyzing the obtained values of the maximum change in the speed of coke movement, it can be argued that the constructive creation of resistance to the movement of coke in the form of a two-beam structure for supplying coolant to the blower head creates conditions for a more uniform descent of the coke loaded into the quenching chamber of the DCQP, on average reducing the rate of descent of coke by 8-3,4=4.6%. Below is a more detailed analysis of the revealed influence of the design of various units of the DCQP on the nature of the movement of coke in the quenching chamber of the DCQP during its unloading.

4.5 times smaller surface area of a single-level blow head compared to a five-level blow head (diameter 70 mm compared to 150 mm for a five-level one) is the reason for the earlier divergence of the surface profiles of the sectors of the boiler room and coke sides and side sectors, which (divergence) is observed almost from the center of the quenching chamber to its edge. The small surface area of a single-level blow head provides increased sizes of the zone of accelerated coke descent in the sectors of the boiler room and coke sides, which begins at the level of oblique passages.

With a five-level blow head, a noticeable discrepancy between the coke surface profiles of the side sectors and the sectors of the boiler room and coke sides begins below the zone of oblique passages and, not from the center, but from a point approximately 1/3 of the quenching chamber radius from the center. The small discrepancy between the surface profiles in the sectors of the central part of the quenching chamber is the result of the influence of the large surface of the five-level blow head on the formation of the dimensions of the zone of accelerated coke descent.

Comparison of the surface profiles of the considered DCQP indicates an earlier and noticeable manifestation of zones of accelerated coke descent with a single-level blow head, the reason for which is its smaller cross-sectional area than that of a five-level blow head.

The use of a two-beam DCQP with a single-level and five-level blow head is characterized by uniform coke descent in all sectors almost to the level of the blow head. Evidence of this is the parallelism of the coke surface profiles almost to the level of the blow head during its batch unloading. With a two-beam DCQP, the acceleration of coke removal is observed in all four sectors and begins to visually manifest itself at the level of the blow head.

The movement of coke to the level of the blast head is characterized by the constancy of the rate of unloading of coke over the cross section of the quenching chamber, which creates optimal conditions for uniform distribution of the coolant in the array of quenched coke. Estimation of the number and size of zones of accelerated coke descent shows that a single-beam DCQP is characterized by the presence of two zones of accelerated descent located in the sectors of the boiler and coke sides.

4. Conclusions

The two-beam DCQP already has 4 zones of accelerated exit-one in each sector. The dimensions of these zones are the larger, the smaller the surface of the blow head. A larger number of zones of accelerated descent creates a condition for a more uniform descent of coke throughout the entire volume of the DCQP chamber.

The manifestation of the action of zones of accelerated descent begins the earlier, the smaller the surface of the blow head.

The transition from a single-beam design of the DCQP to a two-beam one postpones the moment of the beginning of the formation of an accelerated descent zone, reduces its size and creates conditions for the same behavior of coke in all sectors of the quenching chamber.

Due to the fact that a single-level blower head is 40 mm (1 m in a real DCQP) lower than a two-level one and 80 mm lower than a five-level one, we consider it preferable to use it in a two-beam DCQP, since it ensures not only uniform washing of coke by the coolant, but also the time of contact of coke with the coolant on the coke and boiler sides increases at the same productivity of the DCQP.

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