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Coke Segregation in the Dry Coke Quenching Unit

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Abstract

The main reasons for the appearance of coke segregation when it is loaded into the chamber of a dry coke quenching unit (DCQU) are considered. The formation of the distribution of coke particles of different size along the height and cross-section of the quenching chamber begins already when the coke is unloaded into the DCQU prechamber and is determined by segregation processes. In the quenching chamber, zones with coke of different fractional composition and with different hydraulic resistance are formed, which, in the end, leads to different final temperatures of the quenched coke and, as a rule, to the need to increase the flow rate of the coolant. It is shown that the segregation of coke is already formed when it is discharged from the coking chamber into the coke carrier and then transferred to the DCQU prechamber. Methods for suppressing coke segregation occurring in a coke carrier when loading into a prechamber were tested on a scale model of the DCQU.

***Keywords**: Coke carrier; DCQU, Chamber; Hopper; Fractional composition; Coke segregation.*

1. Introduction

One of the main conditions for the stable operation of the DCQU is the uniformity of the movement of coke in the quenching chamber from loading to unloading and the uniformity of distribution of the cooling coolant in the coke layer. The speed of coke movement is determined by the productivity of the DCQU or the frequency of coke unloading. The uniformity of the distribution of the coolant, in our opinion, is directly related to the laying of pieces of coke in the prechamber of the DCQU during its loading. Since the coke is not homogeneous in terms of its granulometric composition, the segregation factor should be taken into account, especially with a significant difference in size (by analogy with the segregation of coal [1-7]). Segregation of coke leads to the emergence of zones with different grain-size distributions in the DCQU quenching chamber [8], respectively, with different porosity of coke packing, which manifests itself in the formation of zones of different hydraulic resistance, including those that prevent the passage of the coolant through the coke layer, and the creation of conditions for deteriorating technical-economic characteristics of the DCQU operation due to the increase in coke waste. The issues of coke burnout during its quenching in the DCQU are covered in sufficient detail in [9].

The lack of study of the process of segregation according to the granulometric composition of coke in the quenching chamber of the DCQU is evidenced by the fact that none of the more than 150 sources of information given in [10] about the segregation of coke during dry quenching in the DCQU is mentioned in any one.

Earlier, at the stage of development and subsequent modernization of the technology of dry quenching of coke in the DCQU, segregation factors were taken into account in general [11-12], in particular, when calculating the time of quenching of coke. It was assumed that coke having a different fractional composition is conventionally evenly distributed over the volume of the DCQU quenching chamber, and the average diameter of a piece of coke was used for calculations.

Since the resistance of the coke layer is an order of magnitude higher than the resistance of the annular channel, the influence of the distribution of the regulating means in the oblique passages on the distribution of the coolant in the mass of quenching coke is insignificant. The main factor responsible for the distribution of the coolant in the bulk of the loaded coke in the DCQU chamber is the free volume of the inter-lump space, which proportionally depends on the fractional composition of the coke (porosity), that is, the average diameter of the coke lumps in this area.

Segregation of coke is inevitable due to the fact that when it is discharged from the coking chamber at the edges of the dispensed cake, the coke has a different fractional composition than in the zone of the coking charge corresponding to the mass verticals. Due to the sub-cooling of the coke in the zone of the extreme verticals, the finer fractional composition.

In practice, coke segregation appears already in the coke carrier when the coke is dispensed from the coking chamber. Visual observations show that coarse coke is collected on the opposite side from unloading, and fines (mainly the coke cake zones opposite the extreme verticals on the machine side) on the edge of the coke wagon from the side of the dispensed coke. This distribution is transferred to the DCQU prechamber when unloading coke from a coke car. Let us consider the further development of segregation processes inside the DCQU chamber.

The formation of the distribution of coke particles of different sizes along the height and cross-section of the quenching chamber begins already when the coke is unloaded into the DCQU prechamber and is determined by segregation processes, manifested in the movement of large pieces of coke to the walls of the prechamber. This leads to the fact that zones with coke of different fractional composition and with different hydraulic resistance are formed in the extinguishing chamber. Therefore, the amount of the heat carrier passing through these zones is different, which ultimately leads to different final temperatures of the quenched coke and, as a rule, to the need to increase the flow rate of the heat carrier above the normative 1.5 m^3/kg of coke.

When loaded into the DCQU, the coke is located in the prechamber in the form of a cone with an inclination of the lateral surface approximately equal to the angle of natural slope of the coke, i.e. about 45°. At the stage of loading the coke into the DCQU, its segregation occurs, which manifests itself in the distribution of particles by size, which (distribution), obviously, remains practically unchanged in the quenching chamber to the level of the blowing head. Let's briefly consider the concept of the appearance of coke segregation.

To describe the phenomena concerning the mechanics of bulk materials, consider an elementary area at some point in the bulk medium. The stress acting at a given point can be decomposed into a normal σ_n component and a tangent τ_k component. These components, according to experimental data, are related to each other in violation of equilibrium by a linear dependence:

$$\tau_k = \sigma_n tg\rho + k, \quad (1)$$

where, ρ – internal friction angle per unit area; k – coefficient of adhesion per unit area.

The value of τ_k is the shear resistance, so sliding along the site in question is possible only if

$$\tau_k \leq \sigma_н tg\rho + k \quad (2)$$

The medium is called perfectly loose if k = 0. For an ideal bulk medium, the angle of internal friction ρ is equal to the angle of natural slope. Thus, bulk media are those which, in the presence of internal friction, have only a small adhesion.

From the last statement it can be concluded that the adhesion of individual pieces of coke is inversely proportional to its size. A larger piece of coke has a larger adhesion surface.

However, being on the site and touching only one of its sides to the surface and having a larger mass, the ratio of its adhesion surface to the volume (mass, size) of a piece of coke is less than that of a smaller piece of coke.
Therefore, further coke segregation also occurs in the prechamber itself, manifested in the fact that larger pieces of coke roll to the edges. Small fractions of coke (according to their concentration on one side of the coke wagon) are concentrated in one area of the prechamber (corresponding to the central zone of the coke loaded into the prechamber).
To achieve uniform coke placement in the DCQU chamber, it was necessary to study the coke segregation on the model. For this purpose, a research methodology was developed, a brief description of which is given below.

2. Experimental part

A mixture of coke fines (class 1–10 mm) was used as a model mixture for research. The choice of coke fines as a model substance for research on model DCQU, in our opinion, fully meets the requirements of experiments on models, namely, meets the conditions of similarity and analogy (scale of the model) of the studied processes [13]. Similarity is a condition under which the quantitative transfer of experimental results from the model to the original is possible. In this case, based on the theorem of the similarity theory, a similar point of such objects was the sieve composition of coke loaded into industrial DCQU and the content of fractions of coke fines in the model substance.

To model the behavior of coke in a coke wagon when unloading it in DCQU, coke> 10 mm was used as a large fraction, and coke with a fraction of 1–3 mm was used as a small fraction [14]. The amount of fine coke was taken to be equal to the proportion of coke located opposite the extreme vertical of the coke chamber.

The fraction of class 1–3 mm of model coke was painted white with water-emulsion paint (the proportion of coke relative to the volume of coked backfill opposite the two extreme verticals on the machine side), which allowed segregation control in two ways - by sieving and visually. To model the behavior of coke in the prechamber and quenching chamber, a model mixture of cokes of fractions 6–10, 3–6, and 1–3 mm in the ratio of 75, 25, and 25%, respectively, was used as a model coke.

Complete filling with coke of the DCQU model required a volume of model coke equal to 78 dm^3. The following volumes of coke were prepared for model studies:
– fraction >10 mm – 25 dm^3;
– fraction 6–10 mm – 120 dm^3:
– fraction 3–6 mm – 80 dm^3:
– fraction 1–3 mm – 12 dm^3 (painted 8 dm^3).

For the sake of completeness of the research, it was envisaged to determine the fractional composition of the model coke backfill in all four sectors by the cross section of the prechamber and the quenching chamber. In particular, data on coke segregation in the zones of sectors (central, middle and parietal), which (zones) were formed by a special divider (Fig. 1), were determined. The volumes of these three zones in all sectors were equal. With an inner diameter of the prechamber model of 290 mm, the diameter of the middle and central parts were, respectively, 237 and 167 mm.

The selected coke samples were scattered in fractions of 8–10, 5–8, 3–5, 2–3, 2–1 and <1 mm. During the analysis, we operated on the data of the weighted average diameter of the sample.

Initially, it was supposed to test the hypothesis of the formation of coke segregation according to the scheme of the loading car – funnel DCQU – prechamber. Subsequently, it was decided to influence the uniform distribution of coke in the prechamber of different ways of loading coke and design solutions, namely:
– the values of the diameter of the loading funnel DCQU;
– loading of coke on the edge or center of the coke wagon;
– use of a divider in a loading funnel (Fig. 2).

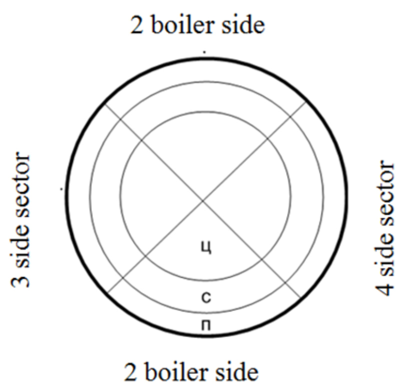

Fig. 1. Scheme of dividing the section of the prechamber for sampling coke in the sectors (c - center, c - middle, n - near-wall zone)

Fig. 2.The design of the splitter in the loading funnel of the confuser-diffuser type DCQU

3. Results and discussion

The results of the studies are shown in Table 1.

Table 1. Data on coke segregation in the DCQU model in sectors by fractions

Sector 1			Sector 2			Sector 3-4		
center	middle	wall	center	middle	wall	center	middle	wall
1. Funnel d = 130 mm, conical divider d = 80 mm								
	5,2			5,9			5,6	
2. Funnel d = 80 mm, conical divider d = 40 mm								
	4,8			5,6			5,2	
3. Funnel d = 80 mm, without conical divider								
	5,2			5,9			5,6	
4. Funnel d = 130 mm, conical divider d = 80 mm								
4,2	4,8	6,1	5,9	6,3	7,3	5,3	5,6	6,5
5. Funnel d = 80 mm, conical divider d = 40 mm								
4,1	5,0	6,6	4,4	6,3	6,7	4,4	5,5	6,4
6. Funnel d = 80 mm, conical divider d = 40 mm Loading coke to the center of the car								
4,5	6,8	7,4	4,1	6,2	7,6	4,4	6,6	7,6
7. Funnel of confusing-diffuser type								
5,2	6,0	6,3	5,5	6,2	6,4	5,4	5,7	6,0

All seven studied design variants of the loading hopper do not eliminate the segregation of coke formed in the coke wagon and the weighted average diameter of coke particles in sector 1 (coke side) is always smaller than their diameter in sector 2 (boiler side).

However, the loading funnel of the last seventh variant - the confuser-diffuser funnel from others is favorably distinguished firstly, rather flat surface of filling in a prechamber and secondly, big uniformity of distribution of particles of different size on section DCQU.

In the studied model, the backfill surface in a confusing-diffuse funnel is characterized by the presence of a central funnel with a depth in the center of 20 mm. The annular top of the funnel is 80 mm from the edge of the prechamber and drops to the edge by 35–40 mm, as shown in Figure 3.

In the studies, the weighted average segregation diameter of the model coke particles was chosen as the segregation measure, since this value is the statistical distribution of particles in the cross section of the prechamber. The ratio of the weighted average diameters of the wall and central coke layers, which is a measure of segregation, for the loading funnel of the confuse-diffuser type gives a ratio of 1.1–1.2, while for all other variants of the loading funnel this figure is 1.4–1.6.

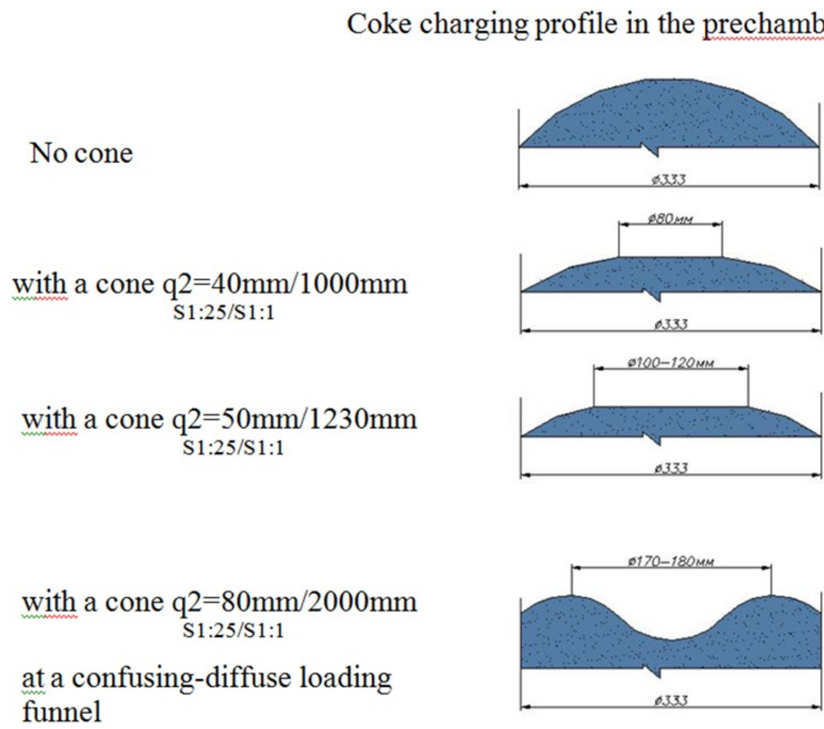

Fig. 3. Coke backfill profiles depending on the diameter of the conical distributor in the hopper

At the next stage of research, the uniformity of the distribution of model coke particles along the height of the DCQU model after full loading and subsequently when issuing equal portions of coke through the unloading device was checked. The data obtained are shown in Table 2.

Table 2. Coke sieving data of different zones according to the height of DCQU

Location	Sector 1			Sector 2			Sector 3-4		
	The average diameter of coke particles in different zones along the height of DCQU, mm								
	center	middle	wall	center	middle	wall	center	middle	wall
Antechamber	5,14	5,96	6,25	5,42	6,24	6,44	5,35	5,71	5,99
The top of the camera	5,12	5,93	6,25	5,41	6,22	6,45	5,40	5,71	6,07
The middle of the camera	5,17	5,96	6,26	5,36	6,20	6,46	5,36	5,75	5,99
Arithmetic mean deviation of coke sieving data from different zones according to DCQU height,%									
Antechamber	0,33	1,00	0,33	2,33	2,00	1,00	2,00	1,33	2,67
The top of the camera	2,33	2,00	0,33	1,33	0,00	0,00	3,00	1,33	5,33
The middle of the camera	2,67	1,00	0,67	3,67	2,00	1,00	1,00	2,67	2,67

The data in Table 2 confirm our assumption that the distribution of coke particles of different sizes formed in the prechamber along its cross section is preserved when they are moved vertically in the quenching chamber. This is confirmed by the practical equality of fractional compositions and weighted average coke diameters in the sectors at all three levels of measurement. Also, the arithmetic mean deviation of the coke sieve data of different zones on the height of DCQU is 1.7%.

The almost uniform distribution of coke particles of different sizes in the cross section of the prechamber, provided by the confusing diffuser loading funnel is a guarantee of maintaining this uniformity as the coke is lowered in the quenching chamber and provide, therefore, equality of resistance to the passage of coolant ensuring uniformity of washing of coke by the heat carrier. Comparative results on coke segregation in the prechamber, presented as the ratio of the weighted average particle diameters of model coke, are shown in Figure 3 (D is the diameter of the coke particles).

Thus, the effect of segregation of coke loaded into the prechamber, which is operated in the DCQUs operated, namely, the concentration of smaller fractions of coke in the central part of the prechamber is quite successfully overcome by design solutions, namely:

– loading of coke from the furnace to the center of the coke wagon;

– use of a loading device of confusing-diffuser type with a divider in the diffuser part.

The formation of the value of the specific flow rate of the coolant is influenced not only by the resistance of the coke layer, determined by the fractional composition, but also by the field of velocities of vertical movement of coke in the quenching chamber.

4. Conclusions

Dispensing coke from the coking chamber to the coke wagon leads to coke segregation. The coke of large fractions is collected on the opposite side from the unloading, and the trifle (mainly the area of the coke pie opposite the extreme verticals) on the edge of the loading car from the side of the dispensed coke. This distribution is transferred to the DCQU prechamber when unloading coke from the loading car. In this case, the created distribution of coke fractions is preserved when it is moved vertically before unloading.

Methods have been developed to suppress segregation, increasing the uniformity of the fractional composition of stewed coke in different sectors of the DCQU quenching chamber. Which contributes to the equality of resistance to the passage of the coolant from the blast head to any oblique motion, ie. ensuring uniformity of washing of coke by the heat carrier.

Symbols

τ_κ tangential component of voltage, t/m^2; ρ internal friction coal per unit area;
k coefficient of adhesion per unit area; D diameter of coke particles, mm.

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