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У збірнику опубліковано статті наукових працівників і провідних фахівців України та інших країн в галузі машинобудування, в яких приведені результати наукових досліджень за такими напрямками:

– дослідження процесів механічного оброблення матеріалів та розробка прогресивних способів їх реалізації;

– проектування прогресивних конструкцій різальних інструментів та технологічного оснащення;

– дослідження проблем кінематики, динаміки, міцності та надійності машин і їх вузлів;

- перспективні комп'ютерні технології в машинобудуванні (CAD / CAM / CAE-системи).

Матеріали збірника призначені для наукових працівників, викладачів навчальних закладів, фахівців з питань механічного оброблення матеріалів, загального машинобудування і машинознавства, студентів, аспірантів і докторантів.

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ЗМІСТ

Перспективні комп'ютерні технології в машинобудуванні (CAD / CAM / CAE-системи).

СОДЕРЖАНИЕ

CONTENTS

Promising computer technology in mechanical engineering (CAD / CAM / CAE systems).

УДК 662.74

A. V. GOLUBEV

A. A. TOPOROV (PhD)

E. I. ZBIKOVSKI (PhD)

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IMPROVING THE EFFICIENCY OF THE DRY COKE QUENCHING INSTALLATION DUE TO PERFECTION OF THE DISTRIBUTION OF COOLING GAS

An essential shortcoming of industrial dry coke-quenching installations is the presence of stagnation zones. That leads to magnification of capital outlays and losses of coke due to its partial gasification. It is offered to design a new chamber for the dry coke-quenching installation. Feed of coolant gas should be carried out through uniform channels over the cross-section chambers. Sizes of the channels should be small in comparison with the cross sizes of the quenching chamber.

A study of these devices was conducted on cold physical models. The study results show that under gas withdrawal through peripheral channels decrease of a cone wind proof in the chamber central part is by approximately 30 %. Besides, this allows to provide uniform distribution of coolant gas over the quenching chamber volume. If the above advice distributing devices are implemented the coke motion is insured to be close to the ideal displacement mode.

Keywords: dry coke quenching, distributing device, coolant gas.

1. Introduction

Coking coal is the most highcapacity method of its chemical treatment. Coke production is a significant component of metallurgy. In the nearest future the majority of crude iron will be obtained in blast furnaces. Coke quality and its cost exert influence on technological and economic parameters of the blast-furnace process. At the same time coke production is one of the greatest emissions source of metallurgical production.

The effective technology raising power efficiency of coke production and increasing coke quality is dry coke quenching.

During the process development a lot of devices of various mode of functioning and designs were offered [1-3]. Now devices for coke cooling with gases circulating in the closed loop have found the widest application. The devices have a chamber-accumulator (prechamber) for the preliminary holding of coke, which placed directly in front of the heat transfer chamber. Such design has been offered by “GIPROKOKS” (State Institute for designing enterprises of coke oven and by-product industry) in the 1950s [4]. These dry coke-quenching installations make it possible:

- about 50 % of heat spent for coking, with obtaining water vapour with parameters 410-540 ^0C and 3,8-11,5 MPa [5];

- to improve quality of a metallurgical coke on indexes of strength, reactive capacity, moisture. According to the average data of Russian and Ukrainian enterprises a mean increase of CSR index for coke of dry quenching in comparison with coke of wet quenching is 1,8 % . A decrease of color rendering index (CRI) is 0,8 %. [6]. The complex improvements of coke quality of dry quenching leads to reducing its consumption in the blast-furnace process on 3-5 % in comparison with coke of wet quenching [7];

- to significantly improve the ecological situation. Water vapour emissions into the atmosphere, which contain phenols, coke dust, cyanides and sulphides are completely expelled. Use of secondary heat sources makes it possible to save other kinds of the fuel (fuel oil, coal, gas) and accordingly to reduce emissions CO_2 and SO_2 into the atmosphere.

At the same time, during the operation of dry coke-quenching installations there have been detected significant shortcomings. First of all, this is considerable capital outlays of coke loss due to its interacting with oxidative components of the circulating gas (CO_2, H_2O), the considerable consumption of an electric power on the gases circulation, intensive evolution of heat and harmful gases into atmosphere.

Substantially, these shortcomings are caused by difficulty of the uniform distribution of coke and coolant gas flows over the cross-section of the industrial coke quenching chamber. This leads to formation of stagnation zones. As it is known in early industrial dry coke-quenching installations coolant gas was fed through the peripheral distributive channels and the central blow device. Later on, one refused the peripheral supply of the heat-transfer agent. In industrial dry coke-quenching installations the coolant gas withdrawal is carried out in the upper part of the chamber through the peripheral windows. This motion pattern of the coolant gas causes the following character of the coke cooling [8]. Near walls of the chamber coke moves rather slowly. There is time to be quenched during contact to the coolant gas. In the centre on the chamber axis there is a considerable volume in the form of a cone, which is not blown by the coolant gas. Thus, in the zone above the blow head the coke moves with the minimum speed over the chamber cross-section. In this volume the coke temperature decreases slightly. Only in the lower part of the chamber the coke starts to contact to circulating gas.

It is necessary to increase the consumption of coolant gas as compared with theoretical one due to presence of incandescent coke in the lower part of the coke quenching chamber and limited time of its contact to the gas. This leads to increasing hydraulic resistance of the system and the electric power consumption. Besides, almost along all height of the coke quenching chamber there are pieces with high temperature. It leads in the increase of the coke losses.

While improving the blow device it should provide the gas motion in such a way, it reduces the maximum volume of a cone wind proof in the chamber central part.

To this end a number of authors has proposed to lift the blow device almost to the level of gas withdrawal flues and to carry out heat-transfer agent supply in the chamber along all height of the blow device [9]. However, this design is sufficiently complicated. It occupies considerable volume in the coke quenching chamber. The high blow head is loosened by the coke flow. Effect of these forces can lead to the device failure. At one of the Ukrainian plants such case has occurred. Since manufacturers doubt in the reliability of this construction. But designers consider it as one of the most promising.

2. Offered solution.

We proposed the new device for distribution of coke fluxes and coolant gas in the lower part of the quenching chamber (fig. 1) [10]. It is expedient to apply the channels system to feed the coolant gas over a cross-section of the cylindrical or rectangular chamber. The channels are formed by an interior surface of the several beams placed uniformly in the lower part of the quenching chamber in a line. In the end surfaces of each beam there are windows passing through walls of the chamber and connecting peripheral distributive channels of the coolant gas with the channels formed by an interior surface of the beams. Circulating gas is distributed uniformly along length of the beams in a coke bed. The little size of the beams ensures the minimum motion resistance of the coke fluxes and, hence, its uniform transition along the volume chambers.

Under the beams there should be devices for rupture of the coke fluxes and it's unloading from the quenching chamber. Thus, it is desirable to rupture the coke flux before its considerable compression, i.e. before its transition in the channels whose the summarized cross-section is smaller than the chamber cross-section. This will promote its uniform motion in the quenching chamber.

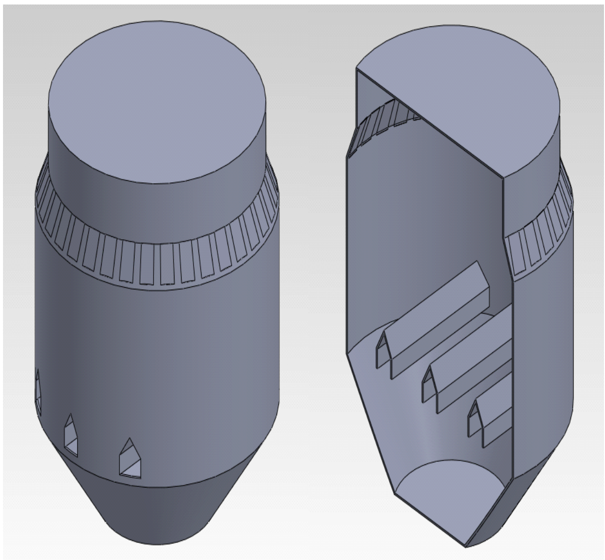


Figure 1 - Proposed design of the quenching chamber .

In the peripheral coolant gas withdrawal on the chamber centre there is the cone wind proof. To solve the problem it is possible to apply the following design [11] (fig. 2). The lower part of the chamber is without modifications in comparison with the design offered above. In the upper part at the interface between the prechamber and the quenching chamber beams are placed mutually in parallel. Their interior surfaces form channels. Through the channels coolant gas gets in the flues of the chamber walls and further into peripheral gas withdrawal channels.

A carcass with elements forming the beam surface can be made of pipes cooled by water or gas. Similar embodiment of units of the high-temperature equipment has found the widest application. The units cooled by water are used in contact dry coke quenching coke. The beams carcass also can be made of the heat-resisting materials with high long-term tensile strength at temperature 800-1000 ^{0}C.

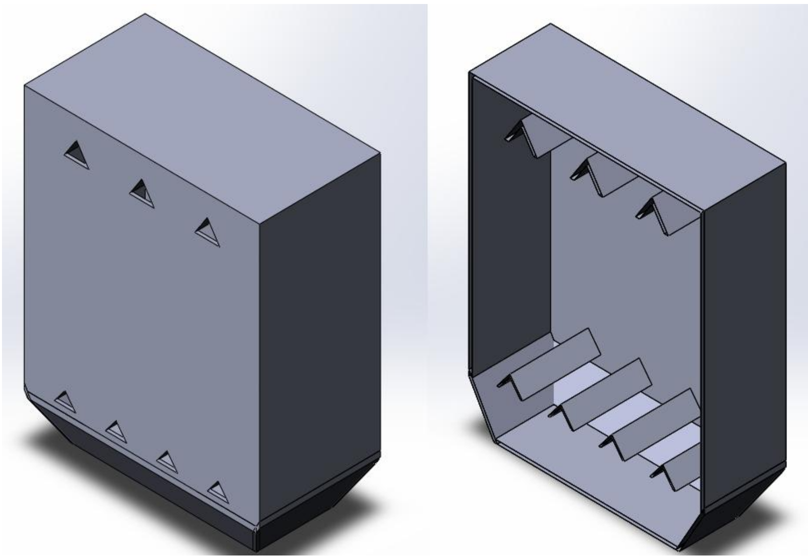


Figure 2 - Chamber with c gas withdrawal beams

3. Experimental methods and installations.

3.1. Research of the flow structure of the coolant gas.

To investigate the gas flow structure in the quenching chamber with the proposed distributing device a physical model of the dry quenching chamber with 0,078 $м^3$ (a scale of "1:10") has been made. The fullest information about hydrodynamic structure of the flow it is possible to obtain if the speeds field in the flow [12] is known. This was taken account during the experiment. The building of the pilot plant and the researches were conducted taking into account of similarity theory requirements [13].

The experiment aim was to determinate the speeds distribution of blowing flow in various cross-sections along the apparatus height.

Principal condition of hydrodynamic similitude of two geometrically similar flows of even absolutely various liquids is the equality of the Reynolds numbers *Re* for similar points. In the model we supported a value of the Reynolds number equal its mean magnitude in industrial dry coke-quenching installation. Researches were conducted at indoor temperature. The flow rate of the modeling agent was defined from the value *Re*. Air as a gas modeling the circulating gas of dry coke-quenching installations was used.

The tests were conducted with the fraction of bulk coke of 10-25 *mm*. This ensures correspondence of the form of channels of the gas motion in the pilot plant with the form of channels in the industrial installation. Thus, it can be said about geometrical similarity of channels. The channels form and sizes define hydrodynamic regime in the chamber of dry coke quenching. Generalized formulas for the single-type, but geometrically dissimilar systems are identical. It is convenient to practical calculations.

To eliminate the impact of the wall fractional void volume on the speeds distribution along the chamber cross-section it's necessary to fulfill conditions [12];

$$\frac{D}{d} > 10 ,$$

where D is the chamber diameter; d is the particle diameter.

To measure the speeds along the chamber cross-section the principle of the speed determination for a difference of the pressures has been applied. In measurements by this principle various nozzles, tubes, sondes and etc. were used as pressure receivers, and different types manometers were used as pressure meters. For the given section it is measured simultaneously full P and static pressure P_{st}, on their difference the dynamic pressure P_{dyn} is defined. Knowing the dynamic pressure and the density of a moving liquid ρ , the liquid speed ϑ is easily calculated:

$$P_{dyn} = P - P_{st} ; \; P_{dyn} = \frac{\rho \cdot \vartheta^2}{2} ; \; \vartheta = \sqrt{\frac{2 \cdot P_{dyn}}{\rho}} .$$

To measure the pressure we applied specially made, calibrated sondes. The sondes sizes are less than sizes of the chamber model, that allowed to eliminate effect of pressure receivers on the flux structure during the speed indications along the length of the installation.

As a secondary device a liquid draft-and-head gage of accuracy rating 1,0 was used.

To measure general flow rate the diaphragm made and installed in according to the requirements [14-15] was used. Together with the diaphragm a liquid U-shaped manometer filled with water was applied.

The experiment was conducted as follows. In the chamber with the distributing device model the coke was charged. The speed distribution was defined in the horizontal cross-section of the coke bed. In this cross-section devices for the pressure measuring were installed along the chamber length. To eliminate effect of the pressure receivers on the gas motion a number of measuring points did not exceed 3. After a full loading of the chamber the model was closed by the cover and the air supply was made. After the experiment completion the coke was delivered from the chamber and the devices for pressure measuring were installed anew in other points or in the same ones for check of reproducibility of test results.

The results were processed according to similarity theory requirements in the form of a relation of the dimensionless speed ϑ to the dimensionless co-ordinates - length X and height H:

$$\vartheta = \frac{w_i}{w_{\max}};\; X = \frac{x_i}{L};\; H = \frac{h_i}{L},$$

Where w_i is the gas speed in a measuring point; $w_{\max}$ is the maximum speed of the gas in the given cross-section; x_i is the distance from an edge of the installation to a measuring point; L is the installation length; h_i is the distance between the lower part of the installation and the experimental cross-section.

The flow section of the coke bed (as well as any other lump material) numerically equals to an unconfined space remaining upon the average to be constant in each cross-section. Due to a chaotic disposition of the pieces and their various shape the flow section is not constant over the charge volume and changes for each fluid element from test to test [16]. Therefore for each measuring point it was conducted five replicate observations. The observations were analyzed by mathematical statistics methods. During the study five speed diagrams for various horizontal cross-sections have been built.

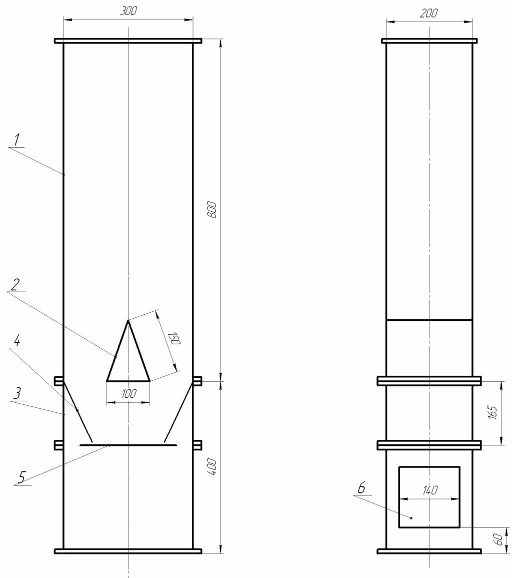
The coolant gas motion in the chamber of dry coke quenching with gas withdrawal channels beams in the upper part of the chamber was analogously modeled.

3.2. Study of the coke flux structure.

To estimate coke flux structure in the dry coke quenching chamber with the described distributing device the laboratory model was made. The model shape and sizes are shown on fig. 3. The chamber of the right-angled cross-section consists of the upper part 1 with the coke flow divider in the form of the Λ-shaped beam 2 and the lower part 3 with the guides of coke 4 and the rotary gate 5. In the lower part there is the window 6 to unload coke passing through the distributing device.

During the experiment 12-20 kg of coke of 10-25 mm class were loaded into the chamber 1 with the closed gate 5 and the charge surface were leveled. On the leveled-off horizontal charge surface it was located a layer of the indicator - coke pieces (dimensions 10-25 mm) covered with a white paint. The indicator mass was about 1,1 kg. After the loading the coke was periodically passed through the distributing device by short-term opening the gate 5. That corresponds to real dynamics of coke motion in the industrial chamber of the dry coke-quenching installations.

Every portion of coke (1,0-1,4 kg) was taken from the chamber 3 through the window 6. The colored pieces were selected from the portion. After that the coke was weighed and loaded again into the chamber 1 and the surface charge is leveled. Thus, the coke mass in the chamber did not change during all experiment. It also occurs in the industrial chamber during the steady operating mode.



1 - upper chamber; 2 - coke divider; 3 - lower chamber; 4 - coke guides; 5 - rotary gate; 6 - window for unloading coke

Figure 3 - Laboratory model of the chamber with the distributing device

We completed the experiment when it was found that the indicator in an unloading portion of coke. The experiment purpose consists of constructing a curve of the response in pulsing feed of the indicator, that characterizes the distribution of pieces for duration of stay in the chamber [12] in dimensionless co-ordinates

$$c = f(\theta),$$

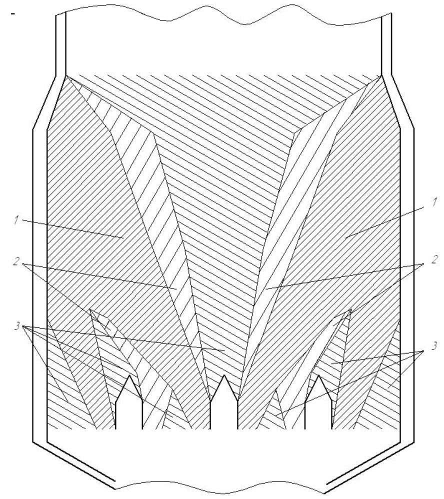
where *c is the* dimensionless (relative) concentration of the indicator in unloading portions of coke; θ - the dimensionless duration of pieces stay in the chamber

5. Results analysis.

5.1. Features of gas moving in the chamber with the offered distributing device

The disposition of stagnation zones in relation to circulating gas in the chamber cross-section is shown on fig. 4. There is a distinct decrease of a basis of the lower cone wind proof due to a reduction of sizes of the device feeding gas on the chamber axis. The stagnation zone in the centre has cup shape rather than regular cone shape. Such form of the stagnation zone can be explained with influence of gas fluxes which move along the path with the least resistance, i.e. actually along the shortest path from two end beams to gas-withdrawal windows. These fluxes create the original aerodynamic latch which changes the gas flux path. The flux moves from the central beam towards the chamber axis. The change of the motion path of the central flux towards the major way is easily explainable since the hydraulic resistance is proportional to square of the speed. In the coke quenching chambers with traditional supply of coolant gas the flux fed peripherally almost right away is pressed to the wall chambers. Near the wall it is observed big fractional void volume of the coke bed due to the segregation.

This flux does not obstruct to the gas motion from the central blow device almost along a direct line to the gas-withdrawal windows.

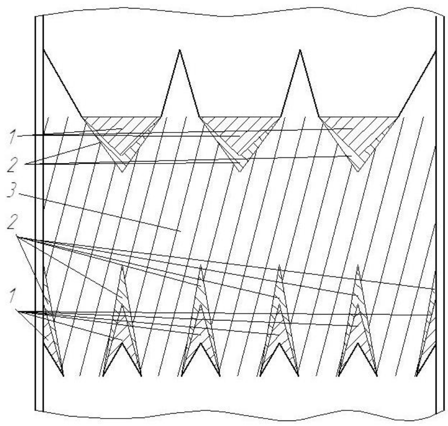


1 - well blown zone ($\vartheta > 0{,}8$); 2 - zone with the decreased speed of coolant gas ($0{,}5 < \vartheta \le 0{,}8$); 3 - badly blown zone ($\vartheta \le 0{,}5$)

Figure 4 - Disposition of the stagnation zones in the coke quenching chamber of the offered design for central cross-section

Experimental data confirm efficiency of the offered design. By the results of physical modeling the diminution of the volume of the cone wind proof for this design is approximately 30 % in comparison with industrial chambers of dry coke quenching.

The research results of the dry coke-quenching installation model are presented on fig. 5. The overall volume of the badly blown zones is 8,6 % from a total volume of the quenching chamber. The overall volume of the zones with an underspeed of coolant gas is 6,0 %. It is much better than in operated industrial installations.



1 - badly blown zone ($\vartheta \le 0{,}5$); 2 - zone with the underspeed of coolant gas ($0{,}5 < \vartheta \le 0{,}8$); 3 - well blown zone ($\vartheta > 0{,}8$)

Figure 5 – Disposition of the stagnation zones in the coke quenching chamber of the offered design

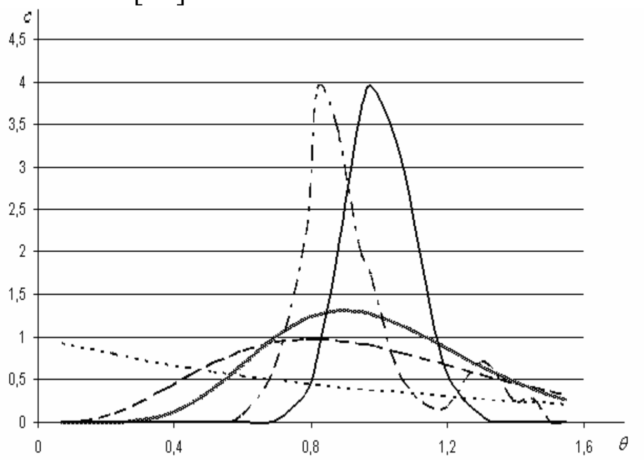
5.2. Singularities of the coke motion in the offered chamber

The experimental curve of the response for the initial loading 20 *kg* of coke (height of a coke bed above the gate is 730 *mm*) and the differential distribution functions of the duration of stay for the cellular model are presented on fig. 6. These functions are counted by the formula [17]:

$$c = \frac{n^n \cdot \theta^{n-1} \cdot e^{-n\theta}}{(n-1)!}.$$

As is apparent from the figure, the major part of the indicator is passed out of the chamber in the interval 0,7-1,05 from the average duration of coke stay in the chamber. Comparison of the experimental curve of the response with the calculated distribution functions confirms that the distribution function of coke pieces for duration of stay in the experimental chamber is well described by the cellular model under the parameter value $n \approx 100$.

It is necessary to emphasize that character of the coke motion in the dry quenching chamber is more correctly described by the diffusion model. For this model the distribution functions of stay duration are computed by the formula [17]:



······ n=1; – – – n=5; ~~~~ n=10; —— n=10; –·–experimental curve

Figure 6 - Experimental and calculated curves of the response for the cellular model in pulsing feeding of the indicator

$$c = \sqrt{\frac{Pe}{4\pi \cdot \theta}} \cdot e^{\frac{-Pe}{4} \cdot \frac{(\theta-1)^2}{\theta}},$$

Where $Pe = \frac{wl}{E}$ is the Peclet number characterizing the intensity of the longitudinal mixing of the pieces in the flux; w is the mean speed of the pieces in the flux; l is the chamber length along the flux; E is the coefficient of the longitudinal mixing of the pieces in the flux.

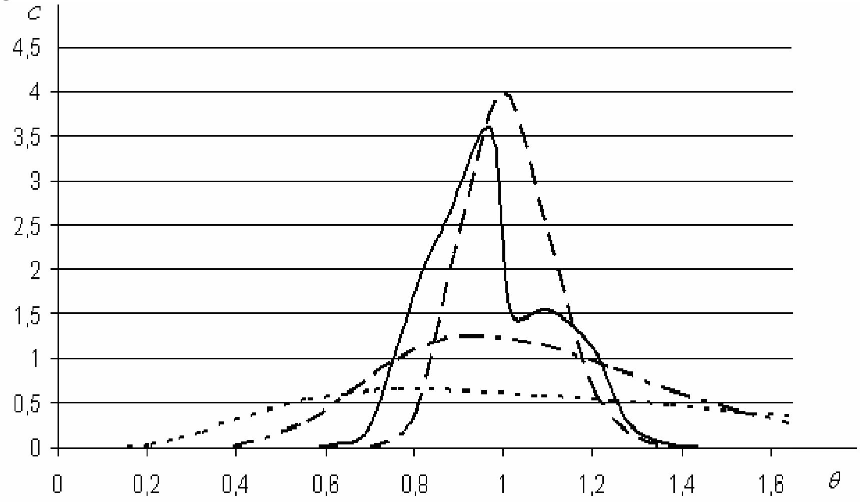
The experimental curve of the response for the initial loading 12 *kg* of coke (height of a coke bed above the gate is 460 *mm*) and the differential distribution functions of the duration of stay for the diffusion model are presented on fig. 7.

As is apparent, the fluxes structure in the laboratory model is well described by the diffusion model for $Pe \approx 180$. For comparison we note that according to the research of the fluxes structure in various apparatuses for values of Pe>10 character of the flux motion differs from the ideal displacement [12].

Nonsymmetry of the coke fluxes (presence of the second peak on the descending branch of the curve) is caused by less disclosing of a channel for the coke emergence from outside where the gate shaft is situated.

Elimination of these deviations of the experimental response curves from the calculated ones can be ensured by manufacturing the coke quenching chamber in the form of a blunted cone (or a prism) slightly extending to the lower part and by installation of two gates on either side of each channel for the coke emergence. Last allows to reduce a breadth of each gate and a twisting moment on the shaft approximately twice.

Thus, the conducted researches of structure of coke fluxes in laboratory conditions showed that the offered distributing device can ensure coke motion uniform over the chamber cross-section, close to the ideal displacement mode. This will affect favorably efficiency of the heat transfer between coke and gas.



Pe=1; ; –· Pe=20; – Pe=200; –experimental curve

Figure 7 - Experimental and calculated curves of the response for the diffusion model in pulsing feeding of the indicator

Conclusions

- In existing industrial dry coke-quenching installation with convective heat transfer there are difficulties of the uniform distribution of coke and coolant gas flows over the cross-section of the quenching chamber;

- In the laboratory-scale plant while feeding of coolant gas through the channels placed uniformly in a line in the lower part of the chamber the volume decrease of a cone wind proof in the central part reaches 30%.

- In presence of the beams for the gas withdrawal in the upper part the uniform distribution of coolant gas over the whole coke-quenching chamber volume with gas feeding by the offered way is attained;

- The distribution function of coke pieces for duration of stay in the experimental chamber is well described by the cellular model with the parameter value $n \approx 100$ or the diffusion model under the parameter value $Re \approx 180$. That corresponds to the ideal displacement mode;

- The obtained results received favorable reviews of dry coke quenching specialists in Ukraine.

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СОВЕРШЕНСТВОВАНИЕ РАСПРЕДЕЛЕНИЯ ОХЛАЖДАЮЩЕГО ГАЗА В УСТАНОВКАХ СУХОГО ТУШЕНИЯ КОКСА

В статье предложено новая конструкция камеры сухого тушения кокса. Ввод охлаждающего газа должен осуществляться через каналы равномерно расположенные по сечению камеры. Размеры каналов должны быть малыми по сравнению с поперечными размерами камеры тушения. Каналы для вывода кокса должны размещаться равномерно по сечению камеры. Разрыв потока кокса должен происходит до его значительного сжатия.

Проведено изучение предлагаемых устройств на холодных физических моделях. Результаты исследований показали уменьшение непродуваемого конуса в центре камеры на ~30 % при отводе газа через периферийные хода. При отводе газа по предлагаемому принципу достигается практически равномерное распределение охлаждающего газа по объему камеры тушения.

Ключевые слова: сухое тушение кокса, газораспределительное устройство, охлаждающий газ.

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ВДОСКОНАЛЕННЯ РОЗПОДІЛУ ОХОЛОДЖУЮЧОГО ГАЗУ В УСТАНОВКАХ СУХОГО ГАСІННЯ КОКСУ

У статті запропоновано нова конструкція камери сухого гасіння коксу. Введення охолоджуючого газу повинно здійснюватися через канали рівномірно розташовані по перетину камери. Розміри каналів повинні бути малими в порівнянні з поперечними розмірами камери гасіння. Канали для виведення коксу повинні розміщуватися рівномірно по перетину камери. Розрив потоку коксу повинен відбування конуса в центрі камери на ~ 30% при відведенні газу через периферійні ходу. При відведенні газу за пропонованим принципом досягається практично рівномірний розподіл охолоджуючого газу за обсягом камери гасіння.

Ключові слова: сухе гасіння коксу, газорозподільне пристрій, охолоджуючий газ.

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