https://doi.org/10.15407/scine20.01.087

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NEW TECHNICAL SOLUTIONS FOR INCREASING THE ACTIVE CROSS-SECTION AREA OF FIRE GRATES OF SINTERING MACHINE

Introduction. *One of the defining elements of the design of sintering machines is a moving conveyor belt consisting of sintering trucks, with a set of grates, on which the charge for the production of agglomerate is continuously loaded.*

Problem Statement. *The presence of the remains of raw charge and agglomerate particles in the space between the grates and the elements of the sintering truck leads to an increase in the mass of the conveyor belt, negative changes in the thermal load of the truck bodies and an increase in the temperature of metal structures and excessive energy consumption for the process.*

Purpose. *Studying the peculiarities of the use of fire grates of the sintering machine with an increased active cross-sectional area and reduced gas dynamic resistance due to improving the grate design.*

Material and Methods. *The features of changes in the gas-dynamic resistance of fire grates made with the use of improved grates, the heat load on the sintering truck, and the conditions for cleaning the grate field from the remains of the raw charge and agglomerate particles have been established by experimental and industrial tests on sintering machines of the AKM-75 type and by modeling with the use of SOLIDWORKS.*

Results. *It has been established that the grates with a variable cross-section and the angle of the contact faces of the hinges of the lock to the under-rail beam, which exceeds 90 degrees, ensure a reduction in the heat load on the sintering truck due to the minimization of the area of their contact with the beam. According to the results of mathematical modeling, the nature of the influence of the active cross section on the volume of absorbed gases has been determined. As a result of the increase in the free access of gas flows for cooling the grates and under-grate beams, the degree of self-cleaning of their contact surfaces increases.*

Conclusions. *The proposed design allows increasing the area of active cross-section of fire grates, providing a reduction in the gas-dynamic resistance to the passage of gas flows and the thermal load of the system, raising the efficiency of removing charge residues from the inter-contact space, and excluding the mechanism of forced grate shaking from the standard scheme of sintering of agglomerate.*

Keywords: grate, contact faces, charge, sintering machine, active section, gas permeability, resistance, and productivity.

Citation: Sigarev, E. N., Rudenko, R. M., Chubin, K. I., Kashcheev, M. A., Rudenko, M. R., and Chubina, O. A. (2024). New Technical Solutions for Increasing the Active Cross-Section Area of Fire Grates of Sintering Machine. *Sci. innov.*, 20(1), 87—97. https://doi.org/10.15407/scine20.01.087

The key conditions that ensure the standard progress of the agglomerate sintering process include forming a layer of sintering charge when it is loaded with minimal compaction along the height and uniform gas permeability across the cross-section of the sintering truck.

The regularities of the relationship between the sintering speed and the filtration of the charge layer have been established [1]. It has been shown that the performance of the sintering machine is significantly influenced by the composition and quality of the charge preparation, the parameters of absorption through the charge layer of the gas flow, and the speed and completeness of solid fuel combustion. One of the reserves for stabilizing the operation of the sintering machine includes [2, 3] increasing the power of the exhauster, reducing the degree of "harmful" suction, reducing the gas-dynamic resistance of the grate system, and stabilizing its operation.

One of the defining elements of the design of agglomeration machines is a moving conveyor belt consisting of sintering trucks with a set of grates (fire grates forming a grate field) on which the charge is continuously loaded. Fire grates, with a stable "live" or active cross-section of at least 8—12%, should provide working gas-dynamic resistance within 0.16—0.40 kPa, effective thermal protection of under-grate beams, and high thermal stability.

The initial gas-dynamic resistance of the fire grates is influenced mainly by the choice of a rational design of the grate. The configuration of the grates should ensure the maximization of the area of the active section during the entire period of operation and the ability to withstand significant loads during operation [4]. Such requirements are associated with an increase in the proportion of finely dispersed materials in the composition of the charge, the absence of the formation of a 20—50 mm thick bed that is placed on the grates from return layer of 15—25 mm agglomerate fraction [5].

In the current working conditions of metallurgical enterprises of Ukraine, iron ore charge is placed on the sintering trucks of the machine without a "bed", which leads to a significant decrease in the active cross-sectional area of the grate field due to the clogging of the latter with solid particles of the charge and melt. In addition, grates work in conditions of high temperatures and velocities of gases absorbed by the exhauster. A significant concentration of dust in the gases (up to 3000 mg/m^3) increases the intensity of the grates' main elements' abrasive wear. At the end of the charge sintering process, the grates are heated to 623—1123 K [4, 6].

As noted by the authors of the study [5], the operation of the exhauster at a constant rotor rotation speed can lead to different productivity according to the amount of gas and create excessive pressure in the network. Thus, its operation depends not only on the design but also on the characteristics of the network. The characteristic of the gas path is the total resistance of various sections (charge layer, vacuum chamber, collector, dust collector):

$$\Delta p_{c} = \Delta p_{c} + \Delta p_{в.к.} + p_{к} + \Delta p_{п}. \qquad (1)$$

It has been established [5] that the section of the gas path from the vacuum chambers to the exhauster creates 10—15% resistance. Thus, the main gas dynamic resistance is created by the charge layer on the sintering trucks and the grate field of the sintering machine.

It should be noted that the power boost of the exhauster to increase the volume of gases absorbed through the charge layer is not economically justified. According to the results of the study carried out on AKM-75 type sintering machines by the authors of this research, a high oxygen content in the waste gases (up to 17—18%) before the exhauster has been established, while the oxygen content in the gases absorbed through the charge layer is 3—6%. This fact may indicate significant harmful suction in the sintering machine.

Today, the sintering shops of metallurgical enterprises of Ukraine have approximately the same design of sintering machines, equipped with 2.5—2.7 m wide sintering trucks that are equipped with different designs of grates. The criterion for choo-

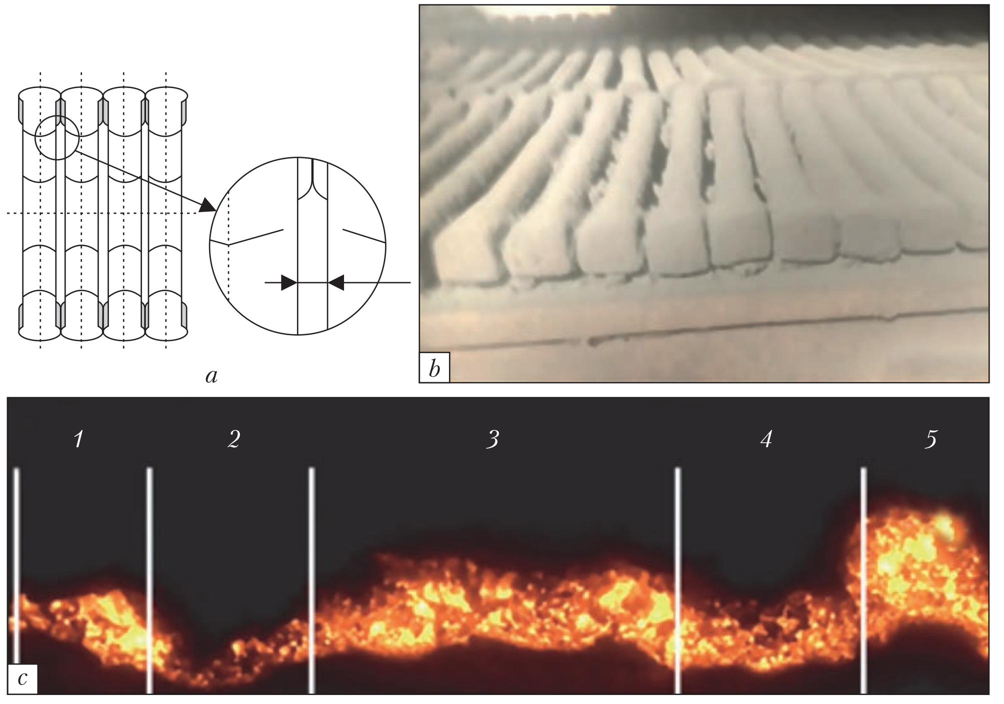


Fig. 1. Scheme of the location of the grates (*a*) and the type of the grate field system of the sintering truck of the AKM-75 type sintering machine during operation (*b*), the type and shape of the agglomeration zone (*c*): *1, 3—5* with a low sintering speed, and a significant gas dynamic resistance; *2* — with high sintering speed and low gas dynamic resistance. The size of the gap at a is 6 mm

sing grates by enterprise specialists is based mainly on the stability indicators. For this purpose, their geometric dimensions are increased, and the optimal chemical composition of the alloy for casting or rolling the grate profile is chosen [6—11].

The existing grate field systems of sintering machines (with an area of up to 100 m^2) provide a maximum active cross-sectional area of 12—15% and, on average, up to 8.5% [5]. Manufacturing practice has established that an increase in the gap between grates of more than 6 mm leads to significant losses of raw charge and complications due to the ingress of melt (Fig. 1, *a*). A decrease in the active cross-sectional area in separate zones of the grate field due to charge blocking and agglomerate particles (Fig. 1, *b*) leads to a sharp increase in gas dynamic resistance and a decrease in the speed of the sintering point (Fig. 1, *c*).

The typical (standard) design includes the grate design with parallel contact surfaces of the sintering truck lock slots and the under-grate beam vertical plane [12—18]. If we use them, the problem of a significant reduction of the active cross-sectional area in operation conditions without a “bed” or with a significant proportion of finely dispersed material in the composition of the charge becomes more acute.

Standard designs of grates have parallel contact faces of the slot and the plane of the under-grate beams at the moment of transition from the working to the blank branch of the conveyor machine. A crushing force acts on the raw charge or a fine agglomerate that has fallen into the space between the grates, which causes blocking the material. The movement of the grate in the vertical plane worsens, and there is a mass blocking of the movement of the grate field and deterioration of its cleaning conditions. The wedge-shaped surface of the slot ensures the movement of raw charge or fine agglomerate only in the direction of adjacent

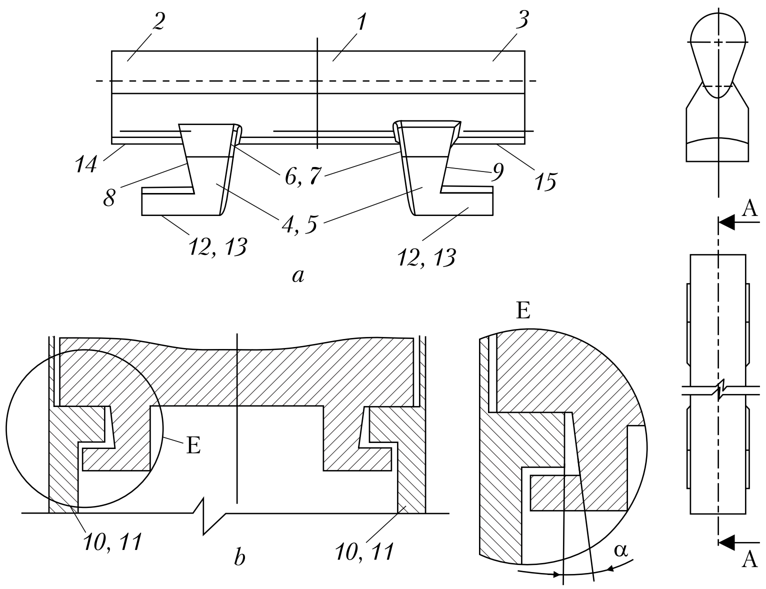


Fig. 2. Grate of the sintering truck of the sintering machine of the improved design (*a*), section of the grate with under-grate beams (*b*): *1* — working part; *2, 3* — heads; *4, 5* — rectilinear tides; *6, 7* — locks; *8, 9* — wedge-shaped slots; *10, 11* — under-grate beams; *12, 13* — lower lock supports; *14, 15* — support faces

grates, in a plane parallel to the plane of the fire grates. Under such conditions, the charge or agglomerate particles are not removed from the space “grate-under-grate beam”.

In order to increase the active cross-section and reduce the gas dynamic resistance of the grate field, ensure the uniform distribution of the gas flow across the width of the sintering belt, and solve the problems as mentioned above associated with the use of standard grate structures, the authors of this work proposed the following changes to the grating structure and the agglomerate production technology.

First, changing the profile of the locks to a wedge-shaped profile of the supports and lock slots; second, the transferring of contact planes from the heads of the working part to the locks; third, making the working part of the grate with the same profile due to the exclusion of contact surfaces from the profile of the heads; and finally, the execution of the contact faces of the lock slots and the corresponding support faces of the heads with an angle greater than 90°.

In order to study the influence of various technical parameters on the improved design of the grate, given its position in space during the operation of the agglomeration machine, a physical model of the grate has been developed, the movement through the grate field system and the distribution of the dust gas flow along the entire length of the central part of the grate have been simulated. In addition, the heat loads on the grate surface, under-grate beams, and the space between the grates have been measured, considering changes in gas temperature and the degree of rarefaction under the grate beams.

Figure 2 shows a diagram and cross-section of the improved structure of the grate and a cross-section of a part of the under-grate beams.

In the improved grate design, the locks have a variable cross-section with an increase in the working part, wedge-shaped slots, and supporting faces of the heads, which form an angle greater than 90° with the contact faces of the lock slots [19]. When installing the grate on the sintering truck, the contact faces of the grate’s slots form an angle α with the contact surfaces of the under-grate beams (Fig. 2, *b*).

Due to the minimization of the contact area of the grate with the under-grate beam, the degree of thermal load on the sintering truck is reduced. As the value of the angle α increases, the force of pushing out the raw charge or fine agglomerate from the opening operation space increases. Such a design solution provides a significant increase in the area of active cross-section of the fire grates of the sintering machine, approaching the design values. In addition, there is an opportunity to pass a gas-air mix that cools the under-grate beams and the grate, through the cleaned space.

A particular part of the raw charge or fine agglomerate in loading, sintering, or unloading falls into the space between the grates and the under-grate beams *10* and *11*. During the movement of the sintering trucks through the blank branch of the sintering machine, the grates are moved in the vertical plane due to the force of gravity (shake) along rectilinear tides *4* and *5* (Fig. 2). When the sintering truck moves to a blank branch, the grates move to touch the slot *8* with the under-grate beam *10*, and the lower supports *12* and *13*, with the under-grate beams *10* and *11*.

When passing the radius from the blank branch to the main branch, the contact collision of slot *8* with the under-grate beam *10* changes to the contact collision of slot *9* with the under-grate beam *11*. At the same time, the lower supports move away from the under-grate beams. The heads of the grate are lowered, and the lower contact faces touch the grate beam upper contact surface for the next agglomeration process cycle. The angle α between the contact faces of the slot and the under-grate beam allows the particles of raw charge or fines to move, with removal from the grate field both in the horizontal plane and in the vertical.

In contrast to known technical solutions, the working part of the grate is made with the same profile due to the exclusion of contact surfaces from the profile of the heads, which expands the area of the active cross-section of the grate field to the entire length of the grate. In addition to the increase in gas permeability in these zones, the air access for cooling the under-grate beams increases. Due to the increase in the degree of self-cleaning, an increase in the specific productivity of the sintering machine and the uniformity of the wear of the working surface of the grates, as well as the reliability of the operation of the grates, are ensured. The forced shaking of the grates can be excluded from the system of fire grates made of grates of an improved design.

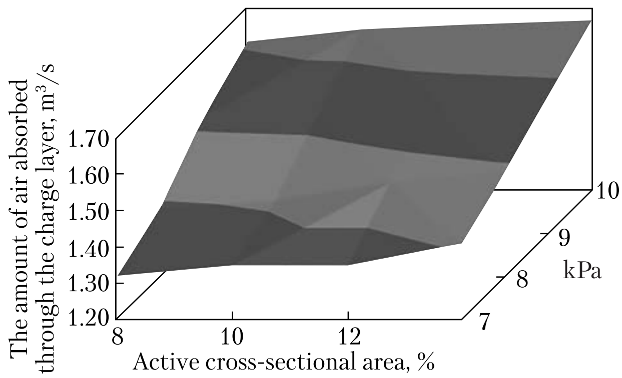


Fig. 3. Response surface reflecting the dependence of the change in the amount of gas and dust flow passing through the layer of sintering charge (G_i), on the active cross-sectional area of the fire grates (S) and the degree of rarefaction under the fire grates

Figure 3 shows the results of industrial studies of the effect of an active cross-section of the grates on consumption of air absorbed in the case of the use of finely dispersed components (fractions < 1 mm) in the amount of up to 80% of the total volume of the sintering charge.

The obtained dependences of the influence of the change in the power of the exhauster (for the vacuum range from 7 to 10 kPa) on the volume of gas and dust flow are represented by the corresponding expressions:

$$G_7 = 0.027S + 1.29 \quad R^2 = 0.8526, \qquad (2)$$

$$G_8 = 0.035S + 1.35 \quad R^2 = 0.9761, \qquad (3)$$

$$G_9 = 0.022S + 1.49 \quad R^2 = 0.9308, \qquad (4)$$

$$G_{10} = 0.019S + 1.59 \quad R^2 = 0.919. \qquad (5)$$

As expected, with an increase in the active cross-sectional area of the fire grates from 8 to 14%, the amount of air and gas absorbed through the agglomerate layer and the charge increases. Previously, the theoretically justified limit of the specified increase [21] was up to 25% of the area of the active cross-section of the grates. However, using the grates that would allow us to achieve the specified theoretical values is significantly complicated in industrial conditions. One of the ways to solve the problem may be to reduce the thickness of the grate, but complications with the sup-

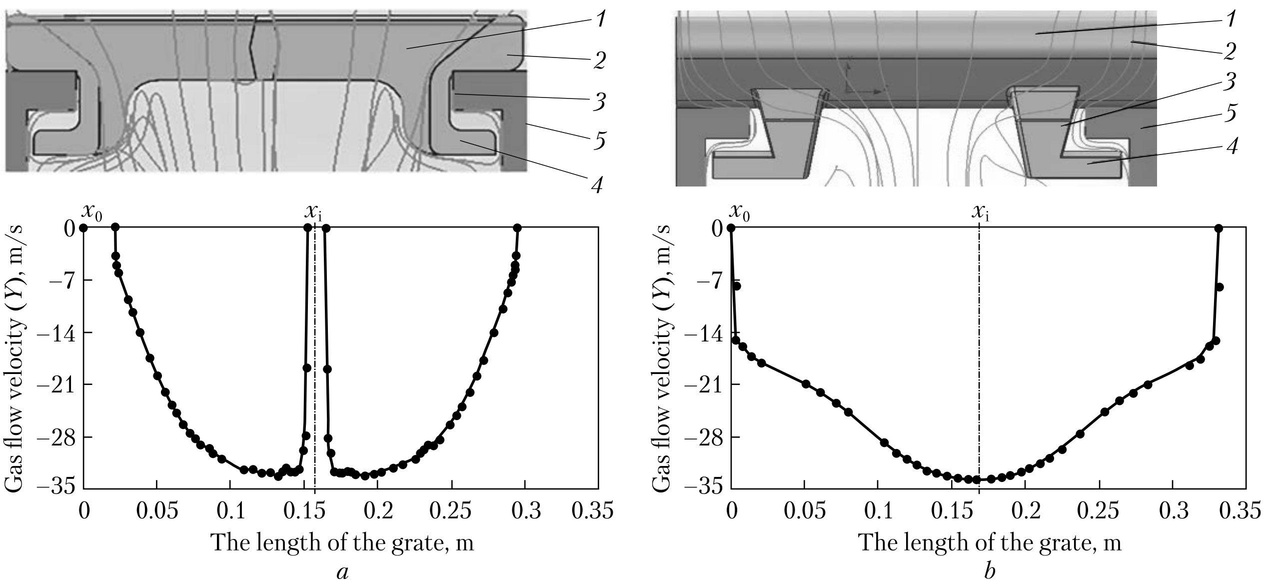


Fig. 4. Velocity of gas flow in the plane of the active cross-section of the grates in the case of the use of standard (*a*) and improved grates design (*b*). The lines on the diagram reflect the nature of the gas flow through the charge layer and between the elements of the system: *1* — working part; *2* — head; *3* — rectilinear tides; *4* — lower supports of locks; *5* — under-grate beams of the sintering trucks

ply of grates with the chemical composition of the metal that meets the requirements [6—11], actualize the need to find and use other options.

The solution proposed in this paper with transferring the contact surfaces to the lower fastening part of the locks can increase the area of the active cross-section of the fire grates (Fig. 2).

In order to determine the main parameters of the «grate field - sintering truck» system, a model of the improved grate design has been developed, and gas dynamics and heat exchange have been simulated in the system using the SOLIDWORKS program and the finite volume method (FVM).

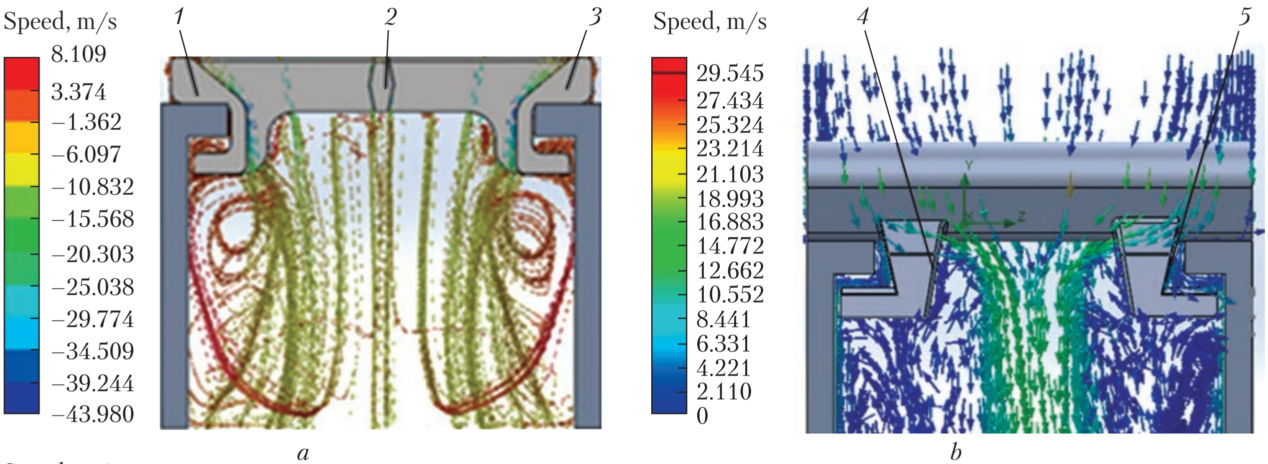
The simulation has been done given the following initial conditions: the conditions of gas impermeable through the boundaries, limited by the ends of the sintering truck and under-grate beams; free movement of gases through the space between the tides, the supports of the locks and the working surface of the under-grate beams (Fig. 4); the temperature and velocity of the gas flow at the entrance to the grate system is 1073 K and 3.0 m/s, respectively. The pressure at the system inlet is set to P_{g1} = 101325, while the pressure at the outlet from the under-grates is P_{g2} = 93325 Pa.

The results of modeling the gas flow rate in the plane of the active cross-section of grates with grates of standard (*a*) and improved design (*b*) (Fig. 2) are shown in Fig. 4.

Based on the results of the simulation, it has been found that in the case of the standard design grates (Fig. 4, *a*), there is the existence of three characteristic zones of the absence of the possibility of passage of gas flows. The total area of these zones is 20.3% of the active cross-section of the grate.

In contrast to the conditions of the passage of gas flows according to the scheme of Fig. 4, *a*, in the case of the improved design grates (Fig. 4, *b*), the passage of the gas flow is ensured over the entire width of the active cross-section of the grates, while the minimum flow speed reaches 15 m/s.

The transfer of the contact surfaces (4, 5) from the heads of the working part to the fastening part of the lock slots *6*, *7* (Fig. 2) ensures the passage of the gas (gas dust) flow over the heads of the



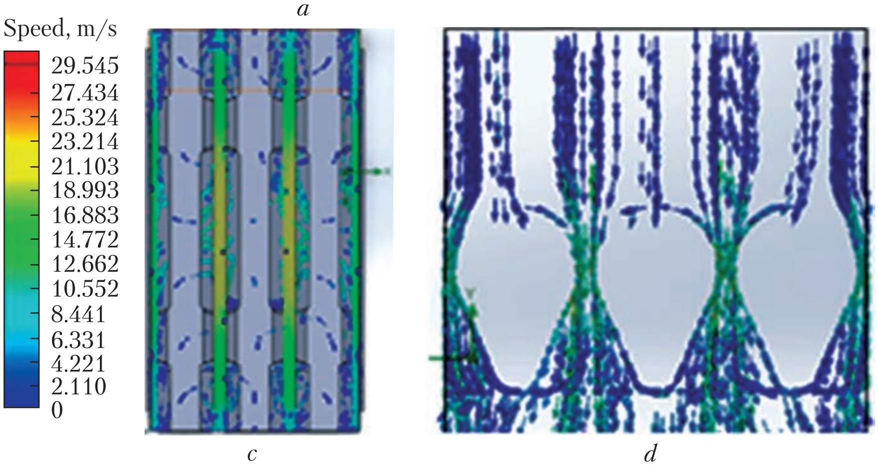


Fig. 5. Trajectories and velocities of the gas flow (m/s) in the "fire grates - under-grate beams" system of the sintering truck of the agglomeration machine with standard grates (sintering truck TK-25) (*a*) and with grates of an improved design (*b, c, d*): *a, b* — front view; *c* — top view; *d* — side view of the sintering truck: *1, 3* — contact planes of the head; *2* — working parts of the standard grate; *4, 5* — rectilinear tides of the grate of an improved design

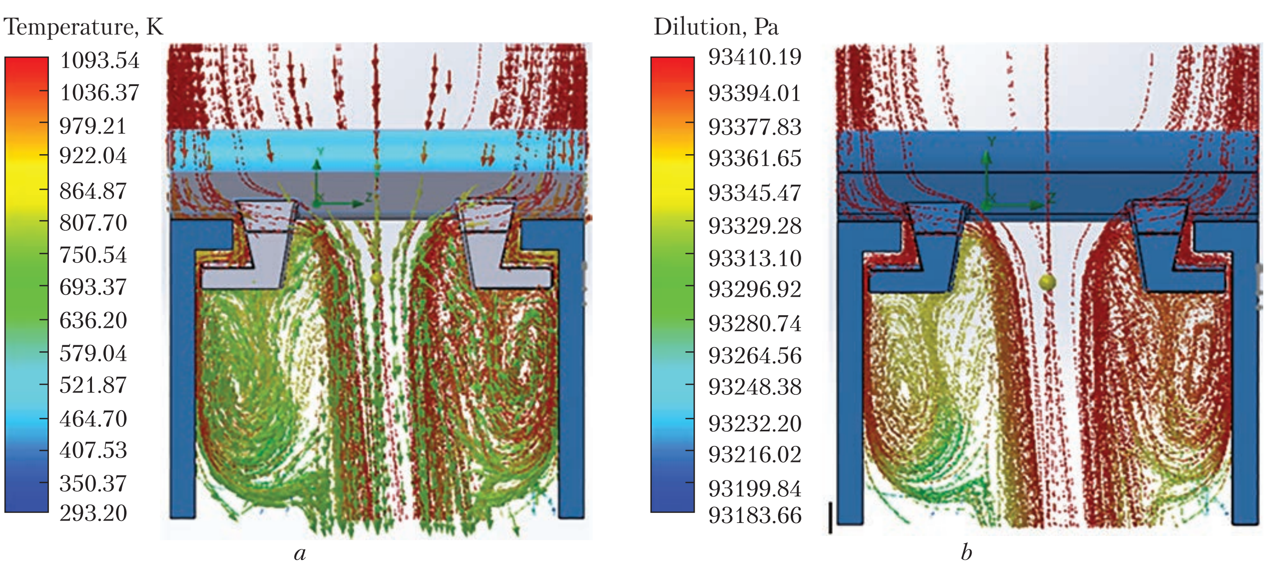


Fig. 6. Temperature distribution (K) and rarefaction value (Pa) in the system "fire grates — under-grate beams" of the sintering truck of the sintering machine according to the simulation results: *a* — temperature distribution in the system by cross-section; *b* is the amount of rarefaction in the system at the cross-section

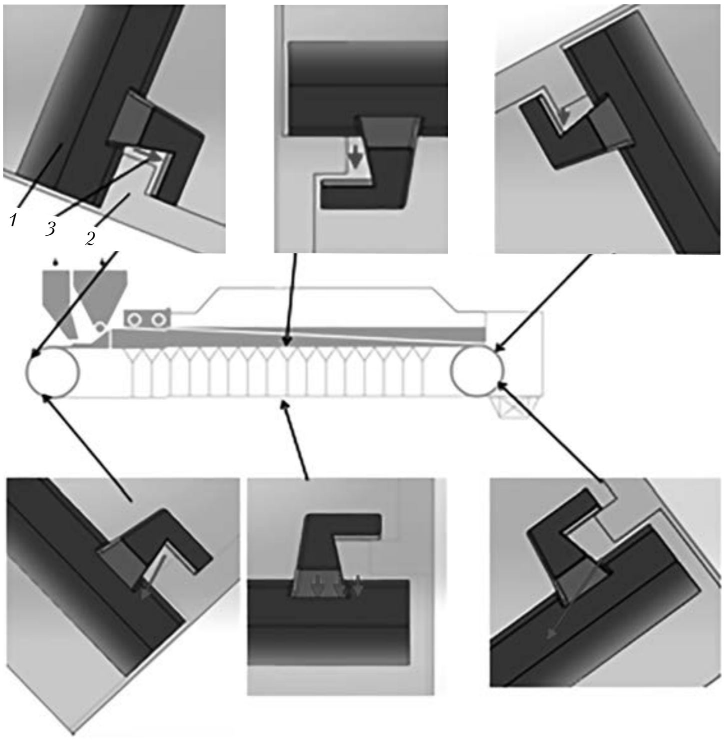


Fig. 7. Simulation of changes in the position of the grate and under-grate beam of the sintering truck and the direction of movement of the charge and agglomerate particles (indicated by arrows) when they are removed from the opening operation space in different periods of movement on the sintering machine: *1* — grate; *2* — under-grate beam; *3* – free space

working part of the grate, the share of which is 25—30% of the total length of the grate.

The results obtained by modeling the trajectory and velocity of the gas flow (m/s), temperature distribution (K), and rarefaction value (Pa) in the system "fire grates — under-grate beams" of the sintering trucks of the agglomeration machine are shown in Fig. 5 and Fig. 6 respectively.

Dependence of the speed of the gas and dust flow (V, m/s) along the surface of the grate of the improved design from the end (x_0, m) to its middle part (x_i, m) (Fig. 4, *b*) in the active cross-section of the fire grate system (Fig. 5, *c*) is represented by the equation:

$$V = 859.56\, x_i^2 - 284.1; x_i - 9.5252 \quad R^2 = 0.8995. \quad (5)$$

The movement of the grate of the improved design in the fire grate system has been simulated when the sintering truck moves from the working branch through the unloading part, the blank branch, and the central part (Fig. 7).

The behavior and peculiarities of removal of the fine component of the charge and agglomerate particles that accumulate in the space between the grates and the grate beams through the provided free space have been studied. The methodology has been refined with the use of the results of modeling the movement of gas flows at different positions of grates in space, and their rational geometric characteristics have been calculated. When increasing the area of the active cross-section of the grates, gas absorption is ensured along the entire length of the grates through the space between the locks and between the grate beams. The highest speed of gas flows in the free plane between grates reaches 33.7 m/s.

CONCLUSIONS

1. Based on the results of experimental and semi-industrial research on AKM-75 machines, it has been established that a significant reserve for stabilizing the operation of the sintering machine is the reduction of the gas-dynamic resistance of the grate system. It has been shown that in the

grates of sintering machines with standard grates that have parallel contact faces of the gap and the planes of the under-grate beams, the space for the absorption of gases is blocked by the charge or agglomerate particles. This fact increases the gas dynamic resistance and makes self-cleaning the system impossible.

2. An improved design of grates with an increased active cross-sectional area is proposed based on a new configuration of grates.

3. The conditions for increasing the active cross-sectional area of the grates of the sintering machine due to the transfer of the contact planes of the grates from the heads of the working part to the fastening part of the locks have been substantiated.

4. The model of the improved structure of the grate has been developed, and the gas dynamics of gas flows and heat exchange in the grate system have been simulated with the use of the SOLIDWORKS program. Using the finite volume method (FVM), we have determined the trajectories, the location of circulation zones, the velocity of gas flows, the temperature distribution, and the rarefaction in the active cross-section of the grates. In contrast to the known solutions, the parameters of heat exchange, temperature distribution, and rarefaction along the height in the system «fire grates – under-grate beams of the sintering truck» are taken into account, which has allowed determining the parameters of the fire grate system with different degrees of gas-dynamic resistance.

5. It has been shown that in the main part of the grate of the standard design, there are three zones with no passage of gas flows, the total area of which is 20.3% of the active cross-section of the grate. In the case of the improved design grates, gas permeability is ensured over the entire width of the active cross-section of the grates while the minimum speed of the gas flow reaches 15 m/s.

6. The methodology has been refined based on the simulation results of the movement of grates at their different positions in space. The rational geometric characteristics of the grates of the improved design, which ensure an increase in the area of the active cross-section of the grates and the absorption of gases along the entire length of the grates have been calculated. In addition to increasing the gas permeability in these areas where the sintering charge is placed, air access for cooling the grate beams increases.

7. It has been established that changing the angle of the contact faces of the lock slots to the grate beam helps to increase the efficiency of removing the charge and fine charge from the opening operation space, ensures the uniformity of wear of the working surface, and increases the service life of the grates, the reliability of the grate grates. Using the improved grate design in the grate field system eliminates the mechanism of forced grate shaking.

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Received 30.03.2023
Revised 21.05.2023
Accepted 11.07.2023

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НОВІ ТЕХНІЧНІ РІШЕННЯ З ПІДВИЩЕННЯ ПЛОЩІ АКТИВНОГО ПЕРЕТИНУ КОЛОСНИКОВИХ ГРАТ АГЛОМЕРАЦІЙНОЇ МАШИНИ

Вступ. Одним із визначальних елементів конструкції агломераційних машин є рухома конвеєрна стрічка, що складається зі спікальних візків, з комплектом колосників, на які безперервно завантажується шихта для виробництва агломерату.

Проблематика. Наявність залишків сирої шихти та частинок агломерату у просторі між колосниками і елементами спікального візку призводить до збільшення маси конвеєрної стрічки, негативних змін у тепловому навантаженні корпусів візку та підвищення температури металоконструкцій й перевитрат енергії на процес.

Мета. Дослідження особливостей використання колосникових ґрат агломераційної машини зі збільшеною площею активного перетину й зниженим за рахунок удосконалення конструкції колосників газодинамічним опором.

Матеріали та методи. Особливості змін газодинамічного опору колосникових ґрат, виготовлених з використанням удосконалених колосників, теплового навантаження на спікальний візок та умов очищення колосникового поля від залишків сирої шихти і частинок агломерату встановлювали шляхом дослідно-промислових випробувань на агломашинах типу АКМ-75 й моделюванням з використанням *SOLIDWORKS*.

Результати. Встановлено, що колосники зі змінним перетином і кутом контактних граней зівів замка до підколосникової балки більше 90° забезпечують зменшення теплового навантаження на спікальний візок за рахунок мінімізації площі їх контакту з балкою. За результатами математичного моделювання встановлено характер впливу активного перетину на обсяг газів, що просмоктуються. Через збільшення вільного доступу газових потоків для охолодження колосників і підколосникових балок зростає ступень самоочищення їхніх контактних поверхонь.

Висновки. Розробка дозволить збільшити площу активного перетину колосникових грат, забезпечить зменшення газодинамічного опору проходженню газових потоків і теплового навантаження системи, підвищення ефективності видалення залишків шихти із міжконтактного простору і виключення зі штатної схеми спікання агломерату механізм примусового струшування колосників.

Ключові слова: колосник, контактні грані, шихта, агломераційна машина, активний перетин, газопроникність, опір, продуктивність.