UDC 669.162.1

Optimization of layer structure of sintering mixture composition in order to stabilize the thermal conditions during sintering

A. Mnyh

Ph.D., Associate Professor,
Zaporozhye State Academy of Engineering,
Zaporozhye, Ukraine

I. G. Yakovleva

Doctor of Engineering Sciences, professor,
Zaporozhye State Academy of Engineering,
Zaporozhye, Ukraine

M. Yu. Pazyuk

Doctor of Engineering Sciences, professor,

A. A. Zherebtzov

Senior Lecturer,
Zaporozhye State Academy of Engineering,
Zaporozhye, Ukraine

Abstract
It was found that the thermal conditions of agglomerate sintering and the gas permeability of the charge layer depend on the segregation processes occurring in the layer of the feed material, which is due to the type of used charging device. The authors solved the optimization problem to determine the control actions on the composite chute providing the formation of the charge layer with the desired properties. A control algorithm of sintering machine charging device was proposed in order to form an optimal structure of the charge layer prepared for sintering, which in complex takes into account the impact of segregation of pellets and gas dynamics of formed layer when loading material to pellet cars. The results of the active experiment with the sintering of agglomerate are given and the influence of the conditions of the charge layer formation on the thermal conditions and the productivity of the process is analyzed. The results of calculations allowed us to establish the optimal values of the sections inclination angles of composite feed chute providing the best fit to the optimal distribution of solid fuel and a reduction on height of pressure losses of the sintering mixture layer.
Keywords: SINTERING PROCESS, FEED CHUTE, SEGREGATION, HORIZON LAYER, CONTROL ALGORITHM

Introduction

The effectiveness of conveyor machines largely depends on improving charge preparation technology, pelletizing and charge feeding onto pallets of sintering machine resulting in formation of a material layer with desired characteristics. The latter is provided by the use of charging devices of various designs. In turn, the effective control of the charge layer formation is provided only in the case of the relationship of gas dynamic characteristics of the material layer and the thermal conditions of sintering with process performance.

Operating experience of domestic and foreign conveyor machines has shown that the absence of the above relationships leads to the fact that the structure adjustment of the charge layer prepared to sintering occurs through a significant period of time, after changing the thermal conditions and gas-dynamic state of the layer.

The lack of control of the structural characteristics of the material on pallets of the sintering machine does not allow rapid analyzing the change in the distribution of chemical components and gas dynamics of the charge layer and therefore, prompt adjusting load mode.

Analysis of researches and publications

Issues of research of influence of such parameters as gas permeability of the layer, the segregation of the raw ingredients, the conditions of formation of the layer structure were studied by a number of scientists.

The authors of [1] associate the gas filtration velocity with the layer parameters and rarefaction of air under the fire grate. Thus, the vertical sintering speed is directly proportional to the gas permeability of the charge measured by the amount of air passing through 1 m^2 of sintering machine indraft area.

The gas permeability of the sintered layer can be significantly increased, if a desired particle segregation on its height is ensured [2, 3] when loading charge on traveling-grate. In [4, 5], the quantitative possibilities of sintering process intensifying were defined due to the redistribution of charge particles of different sizes on the layer height.

For sintering mixture, gas permeability of the layer with a maximum heterogeneity on height is different by 20% from the permeability of the layer with homogeneous structure loaded without segregation.

In [6, 7], an assessment of impact of segregation on the gas permeability of the layer was also given. According to the data, the control of segregation of particles of the sintering mixture layer leads to an increase in its permeability by an average of 15%.

The strength characteristics of sinter largely depend on the patterns of change in the chemical composition and thermal conditions of the sintering process on the height of the layer. In the sintering mixture, flux and fuel are gathered in a fractions of 0-3 mm, which accounts for about 83% of carbon and 73% of calcium oxide. Therefore, the charge segregation by granulometric composition is resulting in fuel content segregation and will affect the thermal conditions of sintering, and, therefore, the strength of the agglomerate. Under standard conditions of the charge loading using a drum-type feeder and a reflective sheet, the initial sintering period is characterized by a lack of heat, thus, the top of the sinter reaching to one third of the total weight of the sintered material is the weakest.

In order to stabilize the thermal conditions of agglomerate sintering process, the authors obtained by calculations an optimal distribution of solid fuels and the fractional composition of the polydisperse charge along the layer horizons. It was proposed to use an improved unit of material loading in the form of a composite feed chute. The latter, according to the results of modeling of the distribution of the charge fractional composition on height of the layer [8], will allow us to get as close as possible to the conditions of required segregation of charge fractions and solid fuel.

Thus, as it is shown by analysis of the literature, the structure of the iron ore layer prepared to sintering and patterns of distribution on its height of fuel and fluxes has the predominant influence on the conditions of the sintering process course and the qualitative characteristics of the agglomerate.

Formulation of the problem

Based on the fact that the thermal conditions of agglomerate sintering and gas permeability of the charge layer depend on the segregation processes occurring in the layer of the feed material, which is due to the type of used charging device, in the work, it is necessary to solve the optimization problem in order to determine control actions on the component chute ensuring the formation of the charge layer with desired characteristics.

Thus, the following tasks are set in the work:

- to develop a control algorithm of loading device of sintering machine to form the optimal structure of the charge layer prepared to sintering;
- to implement a numerical solution of optimization problem;
- to carry out active experiment with agglomerate sintering and analyze the influence of the conditions of the charge layer formation on the thermal conditions and the productivity of the process.

Presentation of research results

Increasing productivity of sinter machines, according to conditioned fraction, can be achieved, firstly, by the providing of a given distribution of the chemical composition and particle size on the layer height, which is intended to adjust the thermal conditions of agglomerate sintering, and secondly, by reducing the gas-dynamic resistance of the charge layer. Thus, when loading the material on pellet cars, we need to comprehensively consider the impact of segregation of granules and gas dynamics of the formed layer.

Studies of gas-dynamic characteristics of charge layer under different conditions of its structure formation led to the conclusion that the pressure losses in the upper horizons of the layer with optimum structure from the viewpoint of distribution of the solid fuel on height are greater than for the initial material. Therefore, from this point of view, it is expedient to decrease segregation of fractions on height of the forming layer.

On the other hand, it should be noted that segregation processes influencing the distribution of the fuel on height of the layer have the predominant effect on the metallurgical properties of the agglomerate compared with gas permeability. Thus, as the optimality criterion, it is necessary to select maximum matching of the solid fuel optimal distribution on height of pellet car in order to provide stabilization of thermal conditions of agglomerate sintering considering pressure losses in the layer.

Formulation of the optimization problem can be represented as follows:

$$\begin{cases} C_{calc}(h) \to C_{opt}(h); \\ \sum \Delta P \to \min. \end{cases}$$

At limitations:

$$\begin{cases} F_i + F_{i+1} + \ldots + F_n = F_\Sigma; \\ d_i F_i + d_{i+1} F_{i+1} + \ldots + d_n F_n = d_{av} F_\Sigma; \\ \alpha_{min} \le \alpha_i \le \alpha_{max}; \\ C_{min} \le C_i \le C_{max}; \\ \sum \Delta P_{min\_oper} \le \sum \Delta P \le \sum \Delta P_{max\_oper} \end{cases}$$

Where: $C_{calc}(h)$, $C_{opt}(h)$ - calculated and optimum fuel content in the layer, %; ΣΔP - total pressure losses in the layer, Pa; F_i - the content of the i-th fraction, %; d_i - the average diameter of the i-th fraction, mm; d_{av} - the average particle diameter of the layer, mm; α_i - the inclination angle of the chute, grad; C_i - the content of fuel in the horizon, %; $\sum \Delta P_{min\_oper} \sum \Delta P_{max\_oper}$ - operating range of differential pressure, Pa.

The developed algorithm to optimize the structure of sintering mixture of the layer is shown in Fig. 1. Initial data for calculation of feeding unit operating mode are the parameters of the raw materials such as the fractional composition, chemical composition, fuel content; the parameters of feeding unit such as the length of the chute sections, varying range of their inclination angles, height and width of the air gap are specified.

Optimization of conditions for structure formation of the charge layer is reduced to the calculation of the amount of control actions (in the most common case - loading chute inclination angles) providing the desired segregation of the material, i.e. the required distribution of fuel and gas dynamics of the layer.

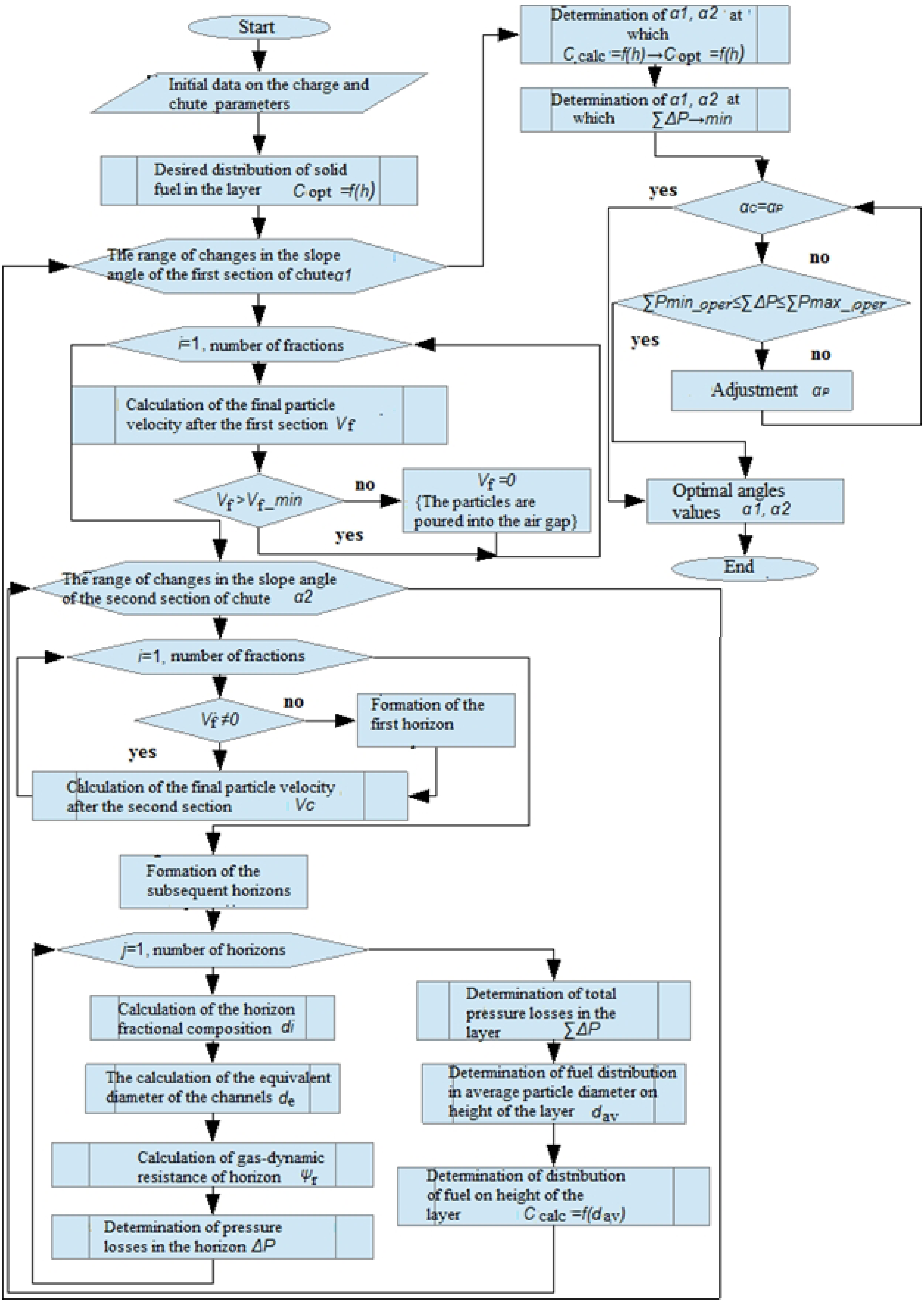

Figure 1. Algorithm for calculating the control actions on the feeding device in order to optimize the structure of the sintering mixture layer

After specifying the initial data and the required distribution of solid fuels, the outer cycle for changing the angle of inclination of the first section of the loading chute α_{1i} is organized. Inside this cycle, calculation of final velocities V_{fi} is performed for each fraction of the initial mixture. Particles, which final velocity does not match the condition of $V_f > V_{min}$, form an upper horizon of the layer bulking in the air gap and the remaining particles pass to the second chute at an inclination angle α_{2i} (a corresponding test is organized in the algorithm).

In the next step, an internal cycle to change the angle of inclination of the second section of the loading chute α_{2i} is created. Inside this cycle, a velocity of particles descent from its surface V_d is calculated. Based on the data on the obtained velocities of particles movement at the appropriate inclination angles α_{1i}, α_{2i}, the calculation of fractional composition of the layer horizons is performed.

Determination of the pressure losses in the horizons is based on preliminary calculation of the equivalent diameter of the channels and gas-dynamic resistance coefficient. After the calculation of all horizons, the calculation of total pressure losses in the layer, the changes of average particle diameter and distribution of the solid fuel on its height parameters is carried out.

Upon completion of the internal (on α_2) and external (on α_1) cycles, we obtain two-dimensional arrays of data in the form of following ratios $C_{calc} = f(\alpha_1, \alpha_2)$ and $\sum \Delta P = f(\alpha_1, \alpha_2)$. This data arrays are processed to determine α_1, α_2, which provide the best match of the calculated and optimum distribution of the solid fuel, as well as minimum pressure losses on height of the layer. Further taking into account the priority of the required fuel distribution, the inclination angles of charging device sections that provide optimal structure of sintering mixture of the layer are chosen.

Software of the algorithm is implemented in Object Pascal programming language.

Based on the fact that the inclination angles of chute sections were in the range of α_1(45÷58°), α_2 (45÷60°), 224 combinations of the surfaces arrangement of charging unit providing the appropriate fuel distribution were obtained. The most visible results of fuel distribution calculations in the layer under the given angle of inclination of the chute sections are shown in Fig. 2.

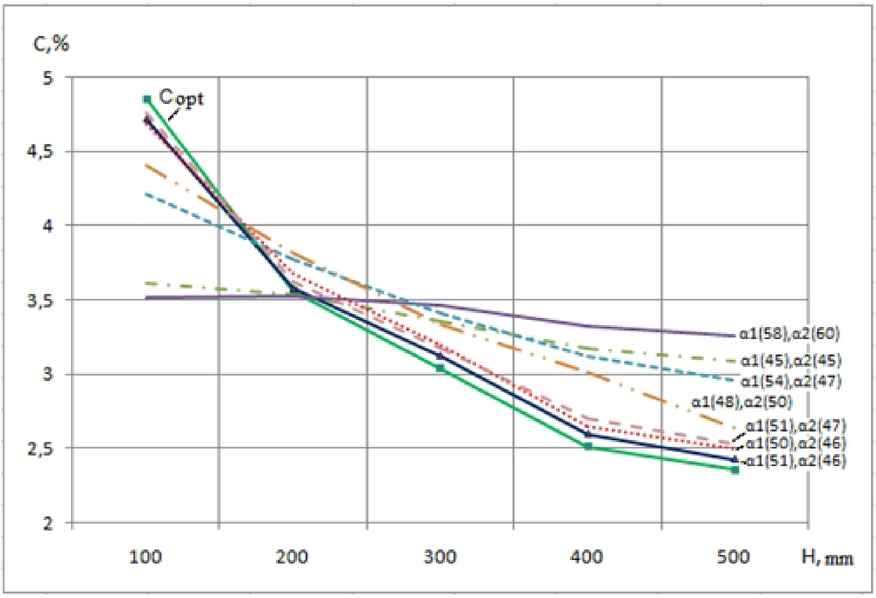

Figure 2. The calculations results of the fuel distribution in the layer

From these results, it is seen that at low inclination angles the segregation processes occurring in the layer are weak due to the fact that large particles do not acquire sufficient kinetic energy for their concentration in the bottom horizons of the layer. In turn, the high values of chutes angles of inclination entail the movement of charge particles in the slip mode, which also adversely affects the segregation of particle size classes and as a result, there is almost uniform distribution of fuel on height of the layer.

The best match to the optimal distribution of the fuel is provided when charging device inclination angle values are α_1 (51°), α_2 (46°).

The calculation results of pressure losses in the layer when using all combinations of inclination angles of loading chute sections are shown in Fig. 3-4.

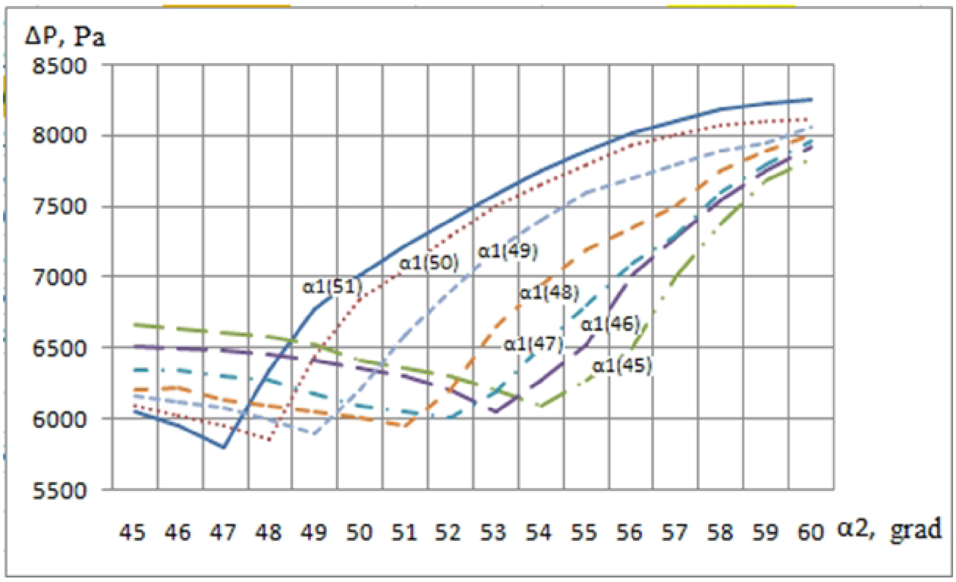

Figure 3. Pressure losses in the layer when changing α_1 (45÷51º)

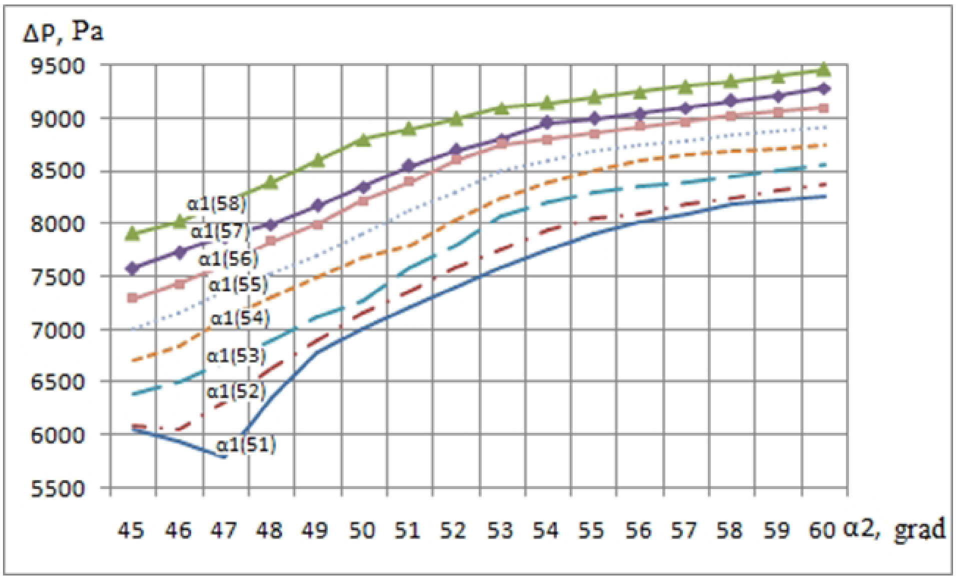

Figure 4. Pressure losses in the layer when changing α_1 (51÷58º)

Based on the calculation results, we can conclude that the minimum pressure losses in the layer are provided when a combination of inclination angles of composite loading chute α_1 (51º), α_2 (47°). Also, it is obvious that a further increase in chute sections angles deteriorates segregation processes in the layer and hence its gas dynamics. The latter is due to the fact that medium and large particles moving at high speeds carry with them finer fractions to the lower horizons, as a result the structure of the loaded layer is compacted.

Analysis of the effectiveness of measures to strengthen the segregation processes in the layer of feed material, through the use of a composite loading chute was conducted by active experiment on "Pilot unit of agglomerate sintering plant" at MC "Zaporizhstal".

The total amount of fuel in the charge was 3.3%, and the pattern of its distribution was as close as possible to the results of a theoretical calculation of optimal distribution of the solid fuel on the layer horizons. The height of the feed material layer was 500 mm, which corresponded to the conditions of operation of sintering machine No 1 of the enterprise.

The experimental results led to the conclusion that by using the loading chute of proposed design, the segregation processes in the layer are improved, the amount of fraction - 3 mm in the upper horizons of the layer (0-100 mm) has increased from 54.3% to 59.6% compared with acting in the enterprise loading scheme. The average content of fuel in these horizons has increased from 3.8%, using the drum feeder - feed chute scheme, and from 4.4% when the vibrating feeder - the feed chute scheme, to 4.76% under the condition of reduction of the total solid fuel content in the charge from 3.3% to 3.6-3.8%.

The test results indicate that stabilization of thermal conditions of the sintering process allowed improving mechanical strength and the yield by 4.22%. The obtained reduction in consumption of coke fines, while maintaining the quality parameters of the sintering process, potentially will save up to 216 thousand UAH per year from one sintering machine for the conditions of the sintering plant.

Conclusion

A designed by authors control algorithm of loading device of sintering machine in order to form the optimal structure of the charge layer prepared to sintering was proposed. The numerical solution of the optimization problem of the algorithm was implemented in Object Pascal programming language.

The results of calculations have established the optimum inclination angles of the composite feed chute sections α_1 (51°), α_2 (47°) providing the best match to the optimal distribution of solid fuels and reduction of pressure losses on height of the sintering mixture layer.

Analysis of the active experimental results on the agglomerate sintering led to the conclusion about the effectiveness of proposed solutions that improve quality indicators of the agglomerate while reducing the overall consumption of solid fuel.

References

1. Korotych V. I. (1969) *Gazodinamika aglomeratsionnogo protsessa* [Gas dynamics of the sintering process]. Moscow: Metallurgiya. 206 p.
2. Korshikov G. V. (1983) Vliyanie stroeniya strukturnykh elementov aglomeratsionnoy shikhty na gazodinamicheskuyu kharakteristiku spekaemogo sloya [Effect of the structural elements structure of the sintering mixture on the gas-dynamic characteristics of the sintered layer]. *Izvestiya VUZov. Chernaya metallurgiya* [Proceedings of the universities. Ferrous metallurgy]. No 6, p.p. 12-15.
3. Frolov Yu. A. (2005) Analiz gazodinamicheskoy raboty aglomeratsionnykh mashin [Analysis of the gas-dynamic operation of sintering machines]. *Stal* [Steel]. No 6, p.p. 42-51.
4. Petrushov S. N., Poluhin A. P., Rudakov L. M., Kapusta A. I. (1983) Issledovanie i sovershenstvovanie ukladki shikhty na aglomashinu [Research and improvement of charge laying on the sintering machine]. *Teplotekhnika i gazodinamika aglomeratsionnogo protsessa: sbornik* [Heat engineering and gas dynamics of the sintering process: collection of works]. Kiev: Naukova Dumka, p.p. 29-33.
5. Sereda B. (2010) The modeling and processes research of titan aluminides stucturization received by SHS technology. *TMS Annual Meeting Conference Proceedings*. p.p. 99-105.
6. Matsumura T. (1999) Development of new feeding equipment for controlling charge segregation of sinter feed. *Current Advances in Materials and Processes*. No 4, p.p. 766.
7. Nakano M. (1996) Sintercake Structure Offering High Productivity and High Yield. *ICSTI Ironmaking Conference Proceedings*, p.p.183 - 190.
8. Mnyh A. S. (2015) Determination of the required segregation of fractions of sinter charge for stabilizing the thermal conditions of sintering. *Eastern European Journal of Enterprise Technologies*. No 1/8(73), p.p. 68-73.