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DETERMINATION OF THE HEAT TRANSFER COEFFICIENT BETWEEN PELLETS AND AIR DURING THE MODERNIZATION OF A PELLETIZING TOWER BASED ON INDUSTRIAL RESEARCH

The object of research is the heat transfer coefficient between pellets and air flow in industrial granulation towers. The problem lies in the difficulty of optimizing the heat transfer process. As a result of experiments and analysis, it was shown that each granulating tower for the production of mineral fertilizers has unique properties that significantly affect the efficiency of heat transfer. There are general mathematical models, but for accurate modeling and optimization of heat transfer, the unique characteristics of each production must be taken into account. The results showed that creating an accurate mathematical model for each specific fertilizer production is a difficult task due to the large number of unmeasured or difficult to reconcile factors.

The method of calculating the heat transfer coefficient for the granulator tower obtained in the course of the work derives from a set of researches on the production of mineral fertilizers. This approach is based on the analysis of technical parameters and granulation composition of the product. The developed method makes it possible to reliably ensure the operating conditions of the device during modernization and changes in production volumes. These results are important for both practical and theoretical purposes. They can be used to accurately predict the operating conditions of equipment during modification and productivity growth. According to the research results, this approach allows obtaining fairly reliable data for forecasting the thermodynamic conditions of the tower equipment in the event of its modernization and transition of the granulation tower to the production of an increased amount of products. The specified method was tested in calculations of production modernization at urea production plants (Indian Farmers Fertilizer Cooperative (Iffco), India), Rustavi Azot LLC (Georgia), Grodno Azot LLC (Republic of Belarus) and others. This method has proven to be quite reliable in predicting the possible need for an additional amount of air supplied to the tower and forming requirements for the operating parameters of rotary vibrating granulators in the event of a significant increase in the load on the float in the tower and an increase in the amount of products planned for release.

Keywords: *heat transfer coefficient, granulator tower, pellets quality control, heat transfer process efficiency, granulator.*

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1. Introduction

Recently, the spread of mineral fertilizer production is gaining momentum all over the world, which is associated with increased production and growing demand for agricultural products [1]. Such an increase in the demand for agricultural products also requires an increase in the demand for mineral fertilizers. This requires either the construction of new industrial facilities for the production of mineral fertilizers, or the expansion and modification of the existing production facilities and their adjustment to the production of a larger amount of mineral fertilizers on granulation towers that have already been built.

The construction of new granulation towers is quite expensive, so most manufacturers follow the path of modernization, improvement of existing granulation towers by increasing the amount of liquid fed to the granulator, and obtaining a larger amount of the finished product in the form of granulated mineral fertilizers. In order to transfer the granulation tower to work in new conditions with a significant increase in float loads, it is necessary to carry out qualitative calculations of both the new hydrodynamic conditions that have formed and thermodynamic indicators in the increased amount of pellet flow and air flow. Such new calculations require, first of all, knowledge of the amount of heat that must be removed from the flow of pellets in order to create conditions for their high-quality crystallization. This is a fairly simple calculation process, which is based on knowledge of both the hydrodynamic indicators of the operation of the tower equipment and the physicochemical properties of the water and is, as a rule, quite defined.

But at the second stage of calculations, there is a need to calculate the numerical value of the heat transfer coefficient to further determine the amount of heat that will be transferred to the air stream. And also the need to calculate the numerical value of the amount of air that needs to be supplied to the granulation tower to ensure the required thermal balance and obtain a granulated product at the bottom of the granulation tower with a given temperature. This temperature indicator is very important from the point of view of carrying out the completed crystallization process and achieving the required strength of the pellets.

In [2], there is a different vision regarding the determination of the heat transfer coefficient between the air flow and the pellets, but almost all mathematical equations, with the help of which these heat transfer coefficients are calculated, are based on the knowledge:

– modes of air flow around the pellet (knowledge of the Reynolds criterion);
– thermodynamic properties of the pellet material;
– air humidity, pressure affecting air density and other factors. An example of such a theoretical determination of the numerical value of the heat transfer coefficient between air and a spherical pellet is the expression:

$$K=\frac{2\alpha_{vozd}\lambda_{karb}}{R_k\alpha_{vozd}+2\lambda_{karb}}, \qquad (1)$$

where α_{vozd} – the air heat transfer coefficient; R_k – radius of the pellet (droplet); λ_{karb} – thermal conductivity coefficient of the pellet (marked for urea in the example), for which it is necessary to calculate the Reynolds criteria $\left(Re=\frac{W_g R_k \rho_{vozd}}{\mu_{vozd}}\right)$ and the Prandtl and Nusselt criteria and then determine the air heat transfer coefficient.

Given the fact that despite the compliance of granulation products with standards or other requirements for product quality, each granulation tower has:

– its geometric features;
– various constructive air inlets and outlets;
– different distribution of pellets across the cross section of the tower;
– various technological features of mineral fertilizer melt production, which affects the quality of melt and pellets.

All this variety of factors of different granulation towers of different manufacturers of mineral fertilizers affects the real heat exchange coefficient. And this is only a partial list of such factors. Therefore, the mathematical formulas given in various literary sources need to be clarified according to the specifics of the specific production of mineral fertilizers. In practice, such a problem is theoretically very complicated and practically impossible to solve due to the variety of factors, many of which cannot be determined or taken into account.

Refinement of methods for calculating heat transfer coefficients using experimental data in various equipment is a task to which many scientific works of scientists in different countries of the world are devoted [3–10]. But specifying the methods of calculating these coefficients for systems of drops or pellets and air, in their mutual movement, is a difficult task, the number of publications in this direction is limited, and similar studies are relevant.

Thus, *the aim of research* is to determine the patterns of heat exchange between pellets and air in granulation towers for the production of mineral fertilizers. The development of methods for calculating heat transfer coefficients and determining the optimal heat transfer mechanism is an important aspect of the scientific part of this work. The practical part includes the application of the obtained results for the modernization and improvement of the characteristics of the existing granulation plants. This work is aimed at providing a basis for improving the technology of mineral fertilizer production and developing optimal heat transfer parameters to improve the quality and quantity of finished products.

2. Materials and Methods

Research conducted at the Chemical Engineering Department of Sumy State University (Ukraine) [3] was dedicated to solving this problem. These studies were based on the rich practical experience gained by the department's employees during the introduction of rotary vibration granulator (RVG) designs developed at the department into industry in different countries of the world. On the basis of numerical studies of the operation of granulation towers and the study of laboratory analysis protocols, which are periodically performed by laboratories at enterprises to control the technological parameters of the operation of the tower equipment and control the quality of products, numerical material was collected on the correspondence of the following parameters:

– granulation composition of the product;
– load on the float;
– air consumption and its temperature at the entrance to the granulation tower and at the exit from it;
– temperature of the liquid supplied to the granulator;
– temperature of the pellets in the lower part of the tower, after the end of the contact process with the cold coolant (air), where the pellets have already completely cooled and formed.

Also, based on the close-to-monodisperse composition of the pellets, which is the result of the RVG work, a method of calculating the heat transfer coefficient was developed, which is based on the results of industrial research and is therefore the most approximate and justified for introduction into the calculations of technological parameters during the operation of industrial RVG. The algorithm of such calculations was based on the data of industrial tests of previous, before the modernization of the granulation tower, data of laboratory studies. These are the intervals of the obtained pellet sizes, with their percentage value to the total amount of product, the temperature of the liquid fed to the granulator, the temperature of the pellets in the lower part of the granulation tower, the temperature of the air supplied to the tower at the entrance and exit from the tower, the load of the tower along the liquid and air consumption. Based on these data, it is possible to determine the real amount of heat «Q» received by the air from the pellets.

3. Results and Discussion

During industrial studies of the granulation composition of the product obtained in the tower, as a rule, values of several intervals of pellets are obtained at the production site.

Therefore, for calculations, it is advisable to bring these parameters of the diameters of the pellets to the average value:

$$d_{av.}=\frac{\sum_{1}^{N} d_i}{N}, \qquad (2)$$

where d_i – the average value of the diameter of the pellets in each interval of determining the granulation composition in the research protocol; N – the number of such intervals.

Next, to determine the heat transfer surface, it is necessary to find the residence time of the medium-sized pellet in the granulation tower. It is possible to calculate the velocities of pellets (Fig. 1) from numerical solutions of the differential equations of pellet motion [3]:

$$\begin{cases} \dfrac{d}{d\tau}W_x(\tau)=-\dfrac{\xi S \rho_{vozd}\left(W_x(\tau)+V_x\right)^2}{2m}, \\ \dfrac{d}{d\tau}W_y(\tau)=g-\dfrac{\xi S \rho_{vozd}\left(W_y(\tau)+V_y\right)^2}{2m}, \end{cases} \qquad (3)$$

where x and y – horizontal and vertical axes; τ – the pellet movement time; $W(\tau)_i$ – corresponding to the coordinate axes, components of the velocity of the droplet; ζ – the resistance coefficient of the pellet; S – the area of the midship cross-section of the pellet; ρ_{vozd} – air density; V_i – according to the axis air speed; m – the pellet mass.

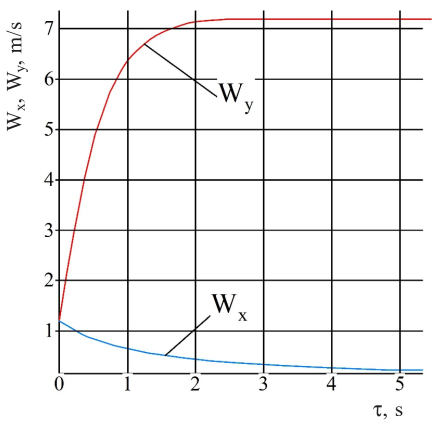

Fig. 1. Change in the value of the horizontal and vertical components of the pellet velocity (calculation according to formula (3)): W_x – horizontal velocity; W_y – vertical speed; τ – pellet falling time

It is also possible to determine the trajectory of the pellet (Fig. 2), by calculating which, taking into account the real height of the granulation tower, it is possible to determine the time it takes for the pellet to reach the bottom of the tower. For the given example of calculations, this time of falling of a pellet in a tower with a height of 42 m is 5.4 s.

Determining the pellet falling time τ, their average diameter d_k and load along the float G_{plava} in an industrial tower can be used to calculate the heat exchange surface. To do this, let's count the number of pellets falling and in contact with cold air:

$$N=\frac{G_{plava}}{m_{gr}}\tau=\frac{1.9G_{plava}}{d_k^3\rho_s}\tau, \qquad (4)$$

and knowing the surface area of one pellet:

$$S=\pi d_k^2. \qquad (5)$$

It is possible to determine the heat exchange surface between pellets and air:

$$F=S\cdot N=\frac{5.99G_{plava}\tau}{d_k\rho_s}, \qquad (6)$$

and knowing the difference between the temperatures of the air at the entrance to the tower and the pellets in the lower part of the tower and the temperature difference of the air at the exit from the tower and the float at the exit from the granulator, it is possible to determine the driving force of the heat exchange process ΔT_{av}, and then the value of the heat exchange coefficient K_{pr} according to the data of industrial studies of the technological parameters of the tower and granulator.

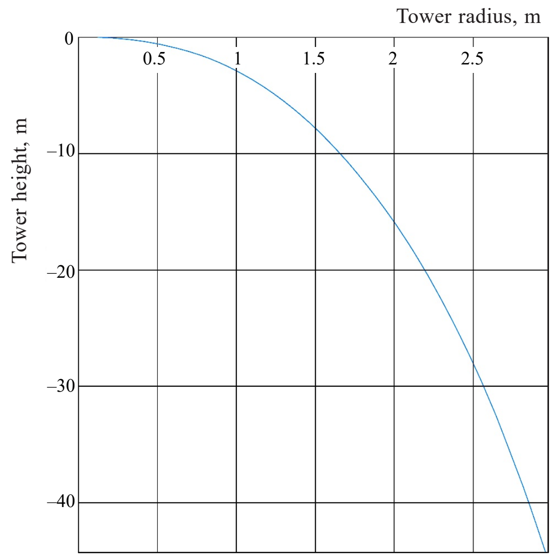

Fig. 2. Graphic representation of the trajectory of the falling pellet. An example for a pellet with a diameter of 1.9 mm and a tower with a height of 42 m

Research limitations: Laboratory studies of product granulation composition provide important information on the quantitative distribution of pellets, but in the manufacturing process, several intervals of pellet diameter are often recorded. Therefore, for practical calculations, it is important to take this aspect into account and reduce the indicator of the diameters of the pellets to an average value. In further studies of words, the determination of the characteristics of the granulation composition should be taken into account, taking into account a wider range of pellets.

Influence of martial law conditions: The current situation in Ukraine, related to the military conflict, may affect the conduct of the study and its results. This can cause difficulties in access to laboratory resources, restrictions on the conduct of experiments, difficulties in the exchange of scientific information, affect the availability of equipment or the possibility of scientific cooperation with other institutions or researchers.

Prospects for further research: Directions for further scientific research may include expanding research to other types of towers for the production of various mineral fertilizers. It is also important to deepen the analysis of the influence of various parameters on the process of heat transfer in the granulation tower, to adapt the developed technology to various conditions and technical modes of production, and to study the optimal strategy for improving conditions to increase productivity and product quality in the future.

4. Conclusions

The method of calculating the heat transfer coefficient for the granulator tower obtained in the course of the work derives from a set of researches on the production of mineral fertilizers. This approach is based on the analysis of technical parameters and granulation composition of the product. The developed method makes it possible to reliably ensure the operating conditions of the device during modernization and changes in production volumes. These results are important for both practical and theoretical purposes. They can be used for accurate forecasting of equipment operating conditions during modification and productivity growth.

According to the research results, this approach allows obtaining fairly reliable data for forecasting the thermodynamic conditions of the tower equipment in the event of its modernization and transition of the granulation tower to the production of an increased amount of products. The specified method was tested in calculations of production modernization at urea production plants (Indian Farmers Fertilizer Cooperative (Iffco), India), Rustavi Azot LLC (Georgia), Grodno Azot LLC (Republic of Belarus) and others. This method has proven to be quite reliable in predicting the possible need for an additional amount of air supplied to the tower and forming requirements for the operating parameters of rotary vibrating granulators in the event of a significant increase in the load on the float in the tower and an increase in the amount of products planned for release.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this study, including financial, personal, authorship, or any other, that could affect the study and its results presented in this article.

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The study was conducted without financial support.

Availability of data

The manuscript has no associated data.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the presented work.

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