Chapter 18
Hydrodynamic and Thermodynamic Conditions for Obtaining a Nanoporous Structure of Ammonium Nitrate Granules in Vortex Granulators

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18.1 Introduction

Formation of the developed nanoporous structure on the surface and inside granules of customary ammonium nitrate (used as mineral fertilizers) expands the areas of its application due to the peculiar properties obtained. Customary and multilayer granules of porous ammonium nitrate (PAN) are used as a main component of the industrial explosive ANFO [1]. Ammonium nitrate granules with a nanoporous organic membrane are successfully applied in agriculture [2, 3].

Based on the analysis of advantages and disadvantages of the existing methods for obtaining porous ammonium nitrate (PAN), this paper introduces a method of the combined moisturizing and thermal processing in the two-phase flow using an active hydrodynamic regime [4–6]. In such a case, a nanoporous structure of ammonium nitrate granules is formed due to moisturizing by water or special water solutions and further thermal processing in a vortex fluidized bed, as described in the works [7–9].

The aim of this work is to model the optimal conditions for forming a nanoporous structure on the surface and inside a PAN granule. Herewith, it must be considered that the presence of a nanoporous structure itself does not guarantee the quality of PAN. It is important to ensure special characteristics of the granules if ammonium nitrate is applied as a component of the ANFO explosive. These characteristic features are the absorbing and the binding abilities of granules. Figure 18.1 depicts the optimal structure of the PAN granule, obtained in a vortex heat-transfer flow by the methods [10, 11]. The macropores on the surface layer of the granules (Fig.

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O. Fesenko, L. Yatsenko (eds.), *Nanocomposites, Nanostructures, and Their Applications*, Springer Proceedings in Physics 221,
https://doi.org/10.1007/978-3-030-17759-1_18

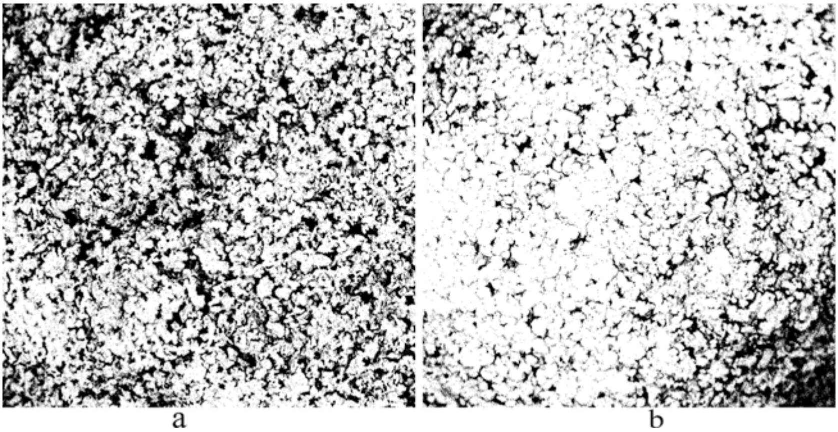

Fig. 18.1 A structure of: (**a**) a surface layer of PAN granules with macropores; (**b**) inner layers of PAN granules with meso- and micropores

18.1a) allow diesel fuel to penetrate the inner layers and, thus, increase an absorbing ability of granules [12, 13]. The structure of the inner layers of granules (Fig. 18.1b) mostly consists of the material with meso- and micropores, which increases the binding ability of granules due to the capillary forces, arising in these pores [14, 15]. Therefore, a promising area for studies lies in the process of consecutive obtaining of individual layers with the given properties on the customary ammonium nitrate granules.

Within the objective of this work, we will present the results of the study on the following:

- the hydrodynamic characteristics of the two-phase flow motion;
- thermodynamic operational parameters of a vortex granulator;
- an influence of the type of a moisturizer on a nanoporous structure of a granule.

The multilayer granules with nanoporous layers can be obtained due to the use of apparatuses with different organizations of the flows motion [16]:

- single-stage granulation units, the number of which is equal to the necessary number of layers on a customary ammonium nitrate granule;
- multistage and multifunctional granulation units.

This paper proposes an application of the multistage vortex granulator with a height-variable section of the workspace (Fig. 18.2) [17].

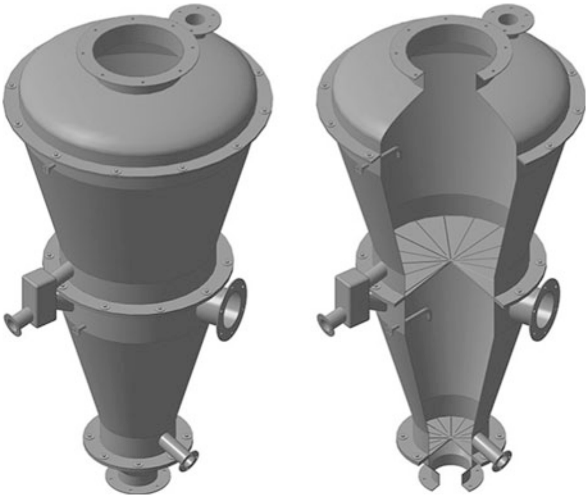

Fig. 18.2 A model of the two-section vortex granulator

18.2 Hydrodynamic Conditions for Obtaining a Nanoporous Structure

In the frames of this work, we conducted a series of experimental studies on the influence of the constrained flow and a construction of a swirler on the fluidized bed structure. The quality of the PAN nanoporous structure when using each type of a swirler is evaluated. An optimal thermodynamic mode is preliminarily considered a "mild" regime, described in the work [9].

The analysis of the granules' trajectory (an average content of the disperse phase in the two-phase system $\psi = 0.15$) and a diagram of the velocity components of the gas flow for each of the considered gas distribution devices (Figs. 18.3, 18.4, 18.5, 18.6, and 18.7) allowed us to define their operational peculiarities and to recommend each of the devices for the application in certain conditions.

It should be noted that an increase in the average content of the disperse phase in the two-phase system impairs the stability of a vortex fluidized bed in all the types of the gas distribution devices, yet the range of operational sustainability of the devices varies.

Gas distribution devices with slots and the ones of a combined type are recommended for the application in the low power apparatuses with a value of ψ up to 0.2. A higher average content of the disperse phase destructs the structure of the stable vortex fluidized bed and evokes spontaneous pulsating zones of the granules. A peculiar feature of the fluidized bed, which is formed in the apparatus with such a gas-distribution device, is an intensive side mix of granules in the so-called "active" zone of a granulator directly above the gas-distribution device. Vertical holes in the central part of the gas-distribution device provide a vertical circulation of granules with low intensity. Such a gas-distribution device combines the advantages of a vortex fluidized bed and a possibility to keep the strength of materials with its small value.

Fig. 18.3 A trajectory of the granules' motion in the application of a gas distribution device with tilted holes

Fig. 18.4 A trajectory of the granules' motion in the application of a gas distribution device with central vertical and periphery tilted holes

A slit-type gas distribution device, as depicted in Fig. 18.8, is characterized by a stable vortex structure with the power almost twice as high as the disperse phase. Such a gas distribution device is recommended as optimal due to a wide range of power in the disperse phase ($\psi = 0.1$–0.3) while maintaining a stable vortex flow of granules.

Fig. 18.5 A trajectory of the granules' motion in the application of a gas distribution device with central tilted and periphery vertical holes

Fig. 18.6 A trajectory of the granules' motion in the application of a gas distribution device with slots

Fig. 18.7 A trajectory of the granules' motion in the application of a combined gas distribution device (slots and holes within the whole space)

Fig. 18.8 A trajectory of the granules' motion in the application of a slit-type gas distribution device

The above-mentioned constructions of the gas distribution devices are widely recognized for applications in the low power apparatuses with a value of ψ up to 0.3. Higher power and higher relative content of the disperse phase require an application of the gas distribution devices of other types.

18.3 Thermodynamic Conditions for Obtaining a Nanoporous Structure

A distribution pattern of the temperature field of the drying agent in the workspace of the vortex granulator depends on:

- the intensity of the drying agent vortex flow;
- a warm-up time of the apparatus;
- a warm-up regime of the apparatus (simultaneously with granules or during the inlet of granules after the drying agent acquires the necessary temperature characteristics).

It should be mentioned that a nanoporous structure of the PAN granules is formed mostly in the "active" zone of the granulator (directly above the swirler and in a zone of an active vortex motion of the two-phase system). Herewith, an increase in the height of the workspace in the granulator's upper part (resulted from damping of an active vortex motion of the fluidized bed) leads to the decreased uniformity of the nanoporous structure formation. Figure 18.9 shows an example of the thermogram of the vortex granulator's workspace (one of the sections in a multisection apparatus) with various intensity (an initial velocity) of the drying

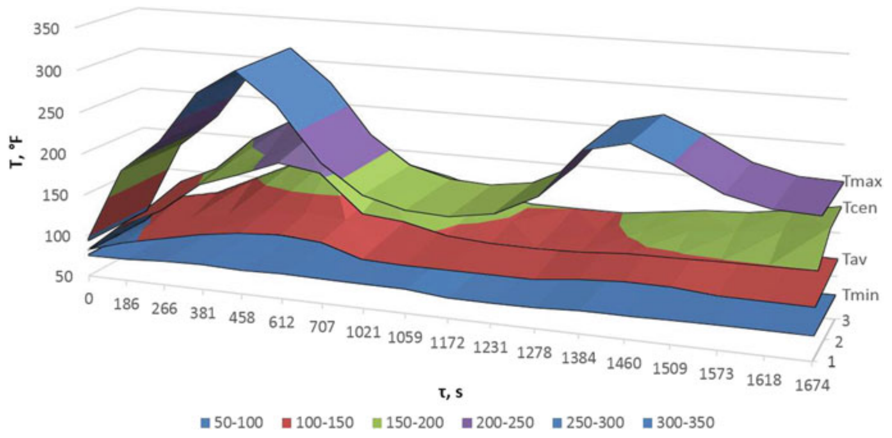

Fig. 18.9 Thermograms of the workspace in the vortex granulator's section and a nanoporous structure of PAN granules: (**a**) low intensity of the drying agent vortex motion; (**b**) an optimal velocity of the drying agent vortex motion; (**c**) high intensity of the drying agent vortex motion

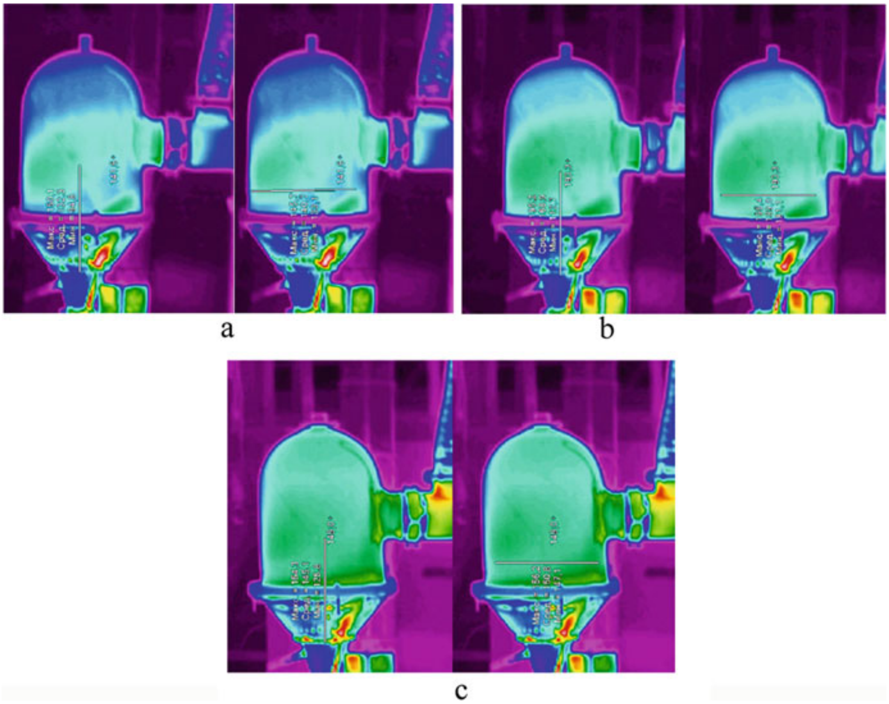

Fig. 18.10 An influence of the vortex gas flow velocity on the distribution pattern of the temperature field in the vortex granulator's section: (**a**) fluidized bed with partial twisting; (**b**) developed vortex fluidized bed (strat of the regime); (**c**) developed vortex fluidized bed (end of the regime)

agent vortex flow and the nanoporous structure of granules, which corresponds to this thermodynamic condition. A nonuniform contact of a granule with a drying agent results in the formation of zones without a developed network of pores. Under a very high vortex motion of the drying agent and over-heating of the granule, its structure receives mechanical cracks that can increase the absorbency of the granule. However, these cracks do not influence a binding ability of the granule and reduce its strength.

Therefore, it is necessary to achieve the optimal intensity of the drying agent, which allows balancing of the temperature field in the workspace of the vortex granulator. Figure 18.10 presents the data of the experimental investigations on determining the relationship between the intensity of the vortex gas flow and the uniform warm-up of the granulator's workspace.

According to the results of the experimental investigations, it is possible to select the optimal velocity of the drying agent vortex flow in the given construction of the vortex granulator.

18.4 An Influence of the Moisture Intensity on the PAN Granules' Structure

The results of the experimental investigations allowed us to define the main patterns of how a nanoporous structure of granules is formed in relation to the intensity of moisturizing of the granule's surface. The maximum amount of the moisturizer was determined taking into account the previously calculated velocities of the gas flow, corresponding to the range between the initial formation of the vortex fluidized bed of granules and their removal from the workspace of the apparatus (critical velocities of fluidization for a vortex flow). A change of the granules' mass under the uniform liquid filming was also considered in the calculations. An optimal temperature of the drying agent was determined on the basis of the conducted investigations on the thermodynamic conditions for obtaining a porous structure of the granules [18]. The process of moisturization was completed after the vortex fluidized bed had lost its stability (a significant reduction of swirling had occurred, and the fluidized bed had lost its vortex characteristics).

With minimal moisturization, only the surface layers of granules are modified, and a small amount of micropores appears after the thermal processing (Fig. 18.11). With the optimal moisturization, the structure of PAN granules is characterized by a considerable amount of macropores on the surface layers of granules, as well as deep micro- and mesopores (Fig. 18.12). The maximum moisturization of the granule's layer results in the developed porous structure of the granules within its whole depths and the reduced strengths of the core due to high temperature stresses during the evaporation of moisture (Fig. 18.13).

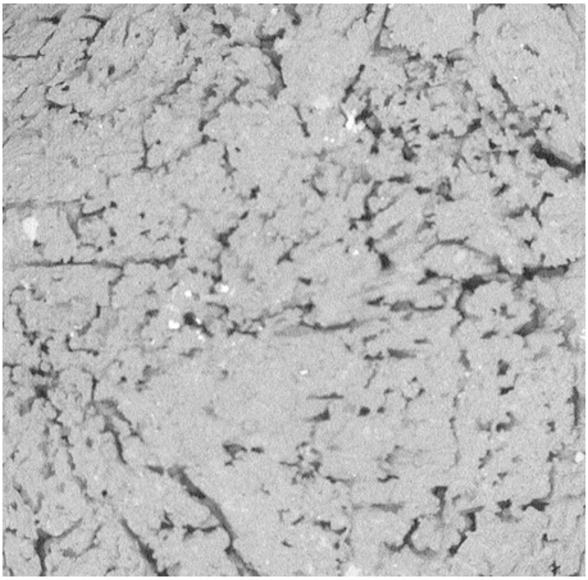

Fig. 18.11 The granules' structure with minimal moisturization

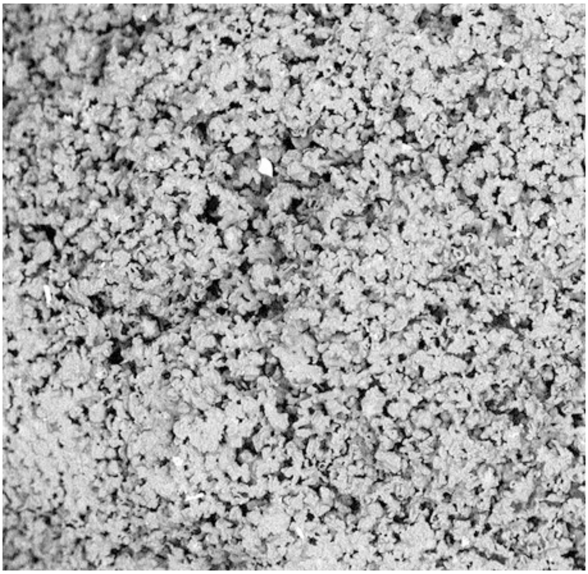

Fig. 18.12 The granules' structure with optimal moisturization

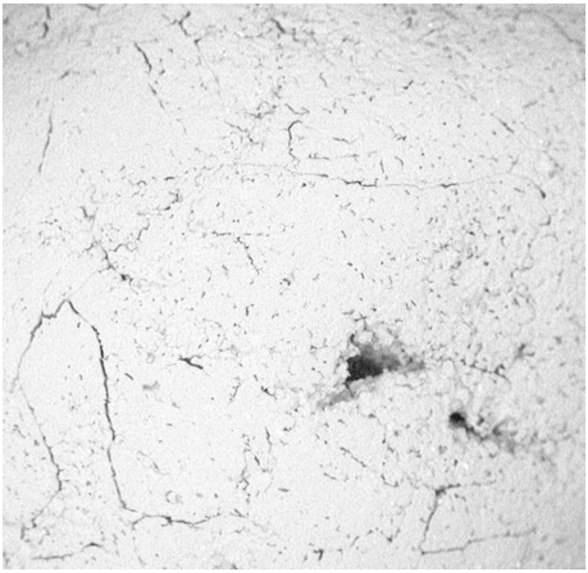

Fig. 18.13 The granules' structure with maximum moisturization

18.5 Conclusions

The results of the investigations, described in this paper, allow us to select the optimal processing regime of the vortex granulator, used for the production of PAN granules. This regime will be optimized according to the following indicators:

- The minimal velocity of the drying agent vortex flow, which is necessary for the formation of the developed nanoporous structure

- The minimal temperature potential of the drying agent for the successful dehydration of granules
- The minimal consumption of the moisturizer for the uniform filming

In this regard, further investigations on the following processes are required:

- An influence of several cycles of moisturization and heat processing on the structure of the previous nanoporous layers
- A complex assessment of the mutual influence of the temperature-moisture characteristics of the flow and the moisturizing pattern (the intensity, type of moisturizer, the consumption of the moisturizer) during the formation of the nanoporous structure of granules

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