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Investigation of the Drying Process in a Multistage Shelf Device: Program Realization of a Theoretical Model

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Abstract

This paper describes a search for an optimal organization of the drying agent motion in the convection dryers. An overview of the main methods on how to reduce the energy consumption for the convection drying of the disperse materials is presented. The use of the multistage shelf apparatuses with a differential thermal regime for the convection drying of the disperse materials is justified. The work contains the results of a computer modeling on determining the drying temperature and moisture characteristics with the use of various methods of the organization of the drying agent motion. The model is realized implementing the author's software product Multistage Fluidizer®. The software product enables to automatize calculation simultaneously by several optimization criteria and to visualize calculation results in the form of 3D images. The engineering computation of sectioning devices methodology with fluidized bed of particles is based on the calculation results. The automated calculations results give a base to design industrial drying device with a differential thermal regime.

Keywords: *Drying, Modeling, Multistage Shelf Apparatuses, Optimization.*

1 Introduction

Modern manufacturing requires development of the new energy- and resource-saving technologies for the disperse materials drying in order to obtain high quality products, to increase the specific production capacity, to reduce the size of equipment, and to intensify the process. Therefore, the scientists should deal with the topical task, that is the improvement of the drying methods and the design of efficient dryers [1].

Various energy-consuming methods are applied for the disperse material drying [2]. Even though energy-consumption in convection drying is not the lowest, the convection dryers are often used for the disperse materials due to numerous advantages [3,4]. An active hydrodynamic regime used in such dryers contributes to the intensification of the process without reducing its cost efficiency, and it has the following advantages [5,6]:

- the hydrodynamic sustainability of the process;
- an increase in the relative velocity of the interacting phases motion;
- a developed surface of the contacting phases interaction;
- the approximation of a hydrodynamic model of flows in the apparatus to an ideal displacement model;

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- the reduced energy-consumption of the process and a lower specific amount of metal in apparatuses.

The choice of such a dryer is justified by its productive capacity, energy and construction costs, work safety, the reliability, the possibility to control technological parameters, the maintainability and the availability of the appropriate transporting equipment.

Convection drying requires transporting of the large volumes of the drying agent. It implies big financial and ecological problems – significant losses of heat energy with the waste drying agent, particularly during the drying of materials with a high moisture content [7,8]. As a result, these losses make 70% out of total losses during the drying [9]. It involves a need for utilization and re-use of heat of the waste drying agent [10].

The drum dryers and apparatuses with a boiling layer are of large sizes and highly energy-consuming. The pneumatic tube dryers do not ensure the necessary contact time of the damp material with the drying agent, and they are characterized by a high altitude [11]. A perspective direction in the improvement of the drying equipment is a design of the combined apparatuses with an active hydrodynamic regime, which ensures the intensified heat exchange and minimal energy expenditures for the fluidized bed [12,13]. An effective method of the process intensification is the organization of local, counterflow and/or combined regimes of the interaction of the drying agent flow with the product, and a selection of an optimal method of the drying agent inlet to the workspace of the apparatus and its re-use [14-16].

The literature analysis of the author presents the following measures on how to reduce the energy costs for the disperse materials drying:

- to re-use heat of the waste drying agent;
- to improve the construction of the dryers;
- to improve the dryer layout and the efficiency of their use (for the multistage dryers – the drying efficiency on each stage);
- an introduction of the improved technology of a recycle dryer;
- a differential thermal regime;
- to reverse and to recirculate the drying agent, including the waste one.

There has been little research reported on the patterns for the dehydration of the materials upon their multistage contact with the drying agent, which changes its properties. The intensity of dehydration differs on each stage of the shelf dryer, and the drying kinetics on each stage must be additionally examined.

Due to repeated contacts of the disperse material with the drying agent in the gravitational shelf dryers, a reduction in energy consumption per unit of the extracted moisture is achieved. It is of special interest to study the moisture removal efficiency on each stage of the dryer under different organizations of the drying agent motion.

2 Theoretical Basics

Consider the typical diagram of the decreasing moisture of a particle from its initial heating (area AB), on the constant velocity area (BC) till the period of the reducing velocity of the process (CD) (fig. 1).

The influence of one or another partial mass-trasfer mechanism on each stage is different. However, the gradient nature of the moisture trasferring from the central layers of the particle into the drying agent flow may be considered as a generalized approach to the development of the optimization model.

Consider the flow moisture characteristics on the i-stage of the dryer (fig. 2).

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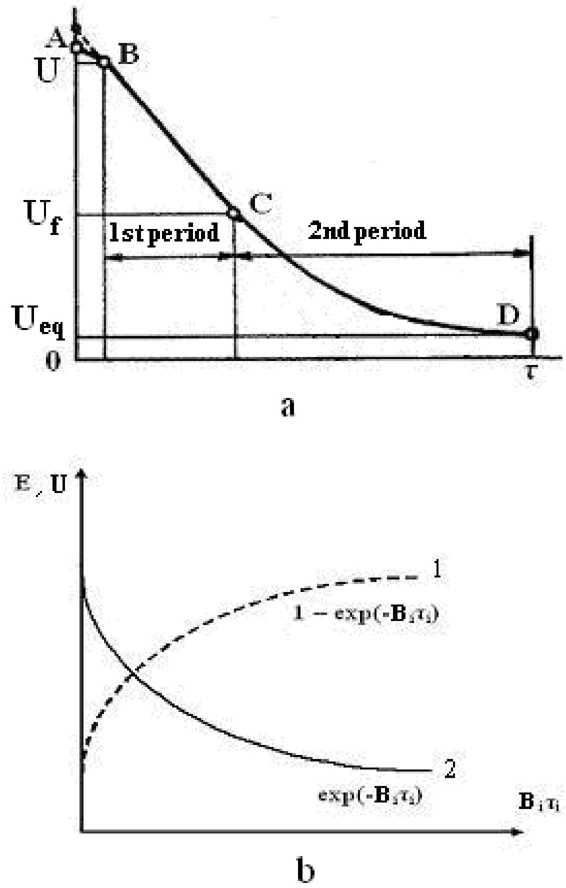

Fig. 1. Graphic visualization of the drying: a – a typical graph of the drying; b – an exponential model of the drying for one stage of the dryer: 1 – drying effectiveness; 2 – theoretical reduction of moisture on the i-stage of the dryer; $B_i\tau_i$ – the kinetic characteristics of the process; τ_i – the contact time of the material with the drying agent on the i-stage of the dryer; U – current moisture of the material; U_{fin} – final moisture of the material in the first period; U_{eq} – equilibrium moisture of the material.

The calculation scheme shows that the maximum difference of moisture contents on the stage complies with the difference of the initial moisture of the dispersed material (or the final moisture of the material, supplied from the preceding stage) and the initial moisture of the drying agent, that is $\Delta x_{\max} = x_{i-1} - b_i$. The removal of moisture, on the other hand, is $\Delta x = x_{i-1} - x_i$ on the stage of the dispersed material. $\Delta x / \Delta x_{\max}$ ratio characterizes the effectiveness of the moisture removal on the i-stage E_i.

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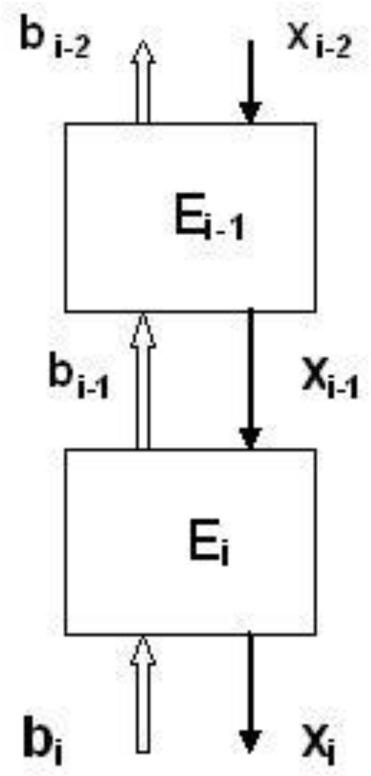

Fig. 2. A fragment of the calculation scheme for the multistage drying: *x* – moisture of the disperse material; *b* – moisture of the drying agent.

Consider the drying efficiency on the *i*-stage of the dryer as a ratio of moisture differences of the disperse material before drying to after drying $x_{i-1} - x_i$ and the maximum possible (theoretic) moisture differences of the flows on the stage $x_{i-1} - b_i$ [5],

$$E_i = \frac{\Delta x_m}{\Delta x_{\max}} = \frac{x_{i-1} - x_i}{x_{i-1} - b_i} \ . \quad (1)$$

To determine the maximum efficiency of the process on each stage of the gravitation shelf dryer, the test installation ensured the conditions under which the drying was performed until no change in the moisture content of the disperse material has occurred.

To determine the maximum value of Δx_m the shelf in the test installation was fixed horizontally without the uploading gap, and the intake of the disperse material charge was complemented by the determination of its moisture. The determination of the maximum value of Δx_m was completed when the value of Δx_m did not change between the two measurements of the moisture content [17,18].

The calculation results of the maximum difference in the moisture contents of the material, corresponding to the maximum efficiency on each stage, are presented in Table 1.

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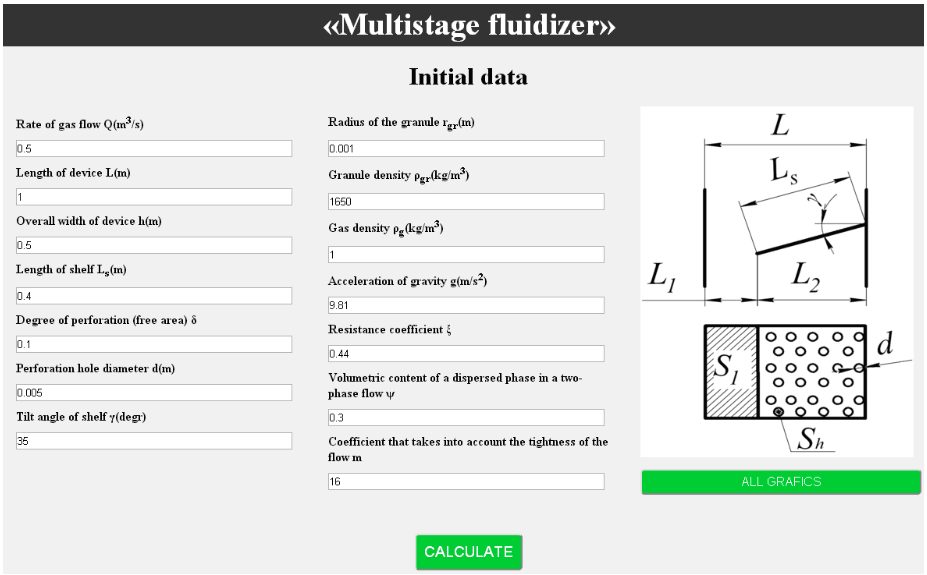
Table 1. The maximum difference in the moisture contents of the material (polypropylene), corresponding to the maximum efficiency on the stage.

A stage number (according to the path of the material)	Maximum difference in the moisture contents Δx , mass fraction
1	0,083
2	0,076
3	0,069

While studying the drying kinetics in the gravitational shelf dryer by computer modeling, we investigated the counterflow motions of the drying agent and the disperse material with the recirculation of the drying agent.

The program Multistage fluidizer® used Hyper markup language HTML, cascading style sheet (CSS) and programing language JavaScript (including the library JQuery). HTML is presented as a tagging of web based app, CSS pages formatting. JavaScript is used to calculate and to transfer data, to create animation and data validation effect. In the validation block of JavaScript data accuracy is checked. In the block input info basic data fields indices are accepted and they are written to the object of input_information. In the block calculation computations are carried out by the model [5].

Index.html (fig. 3) is the main page of web based app. It is responsible for reflection of the main menu, for main calculation of gas flow and for jumping the other pages, where main dependences between key features to calculate gas flow and resistance time of the material on the shelf, are calculated and dependences diagrams are formed.



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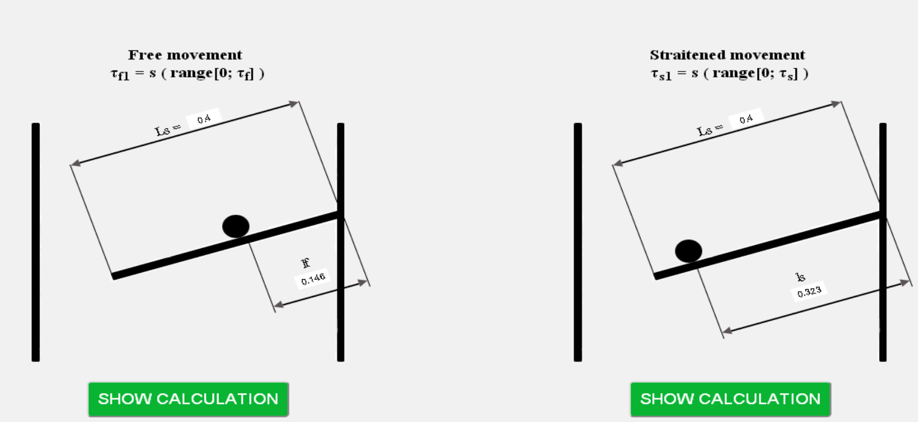

Fig. 3. The main page of the Multistage fluidizer® software.

3 Visualization of results and discussion

The organization of the drying agent motion may have a considerable influence on the quality indicators of the dried material and the properties of the drying agent. That has evolved several studies, the results of which are presented in figs 4-8. Their analysis allows us to select the method of the organization of the drying agent motion, which consumes the least energy, and ensures the necessary complete removal of moisture from the disperse material.

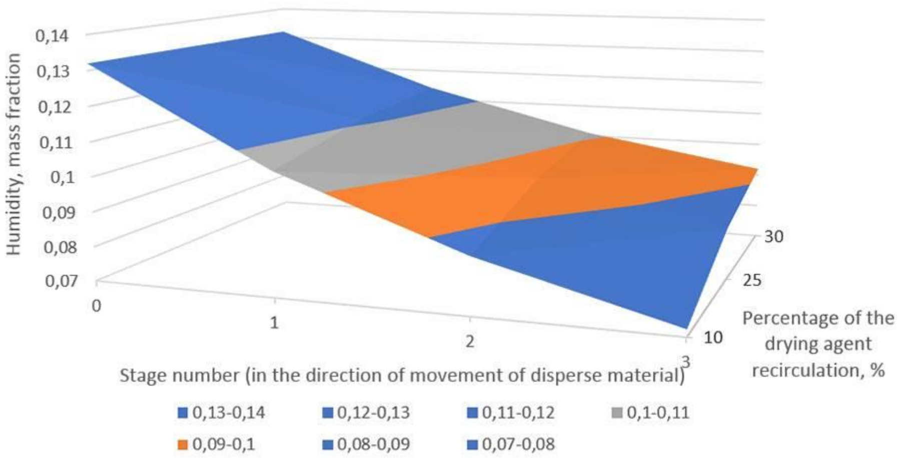

Fig. 4. An influence of the drying agent recirculation method on the change of the moisture content in the disperse material.

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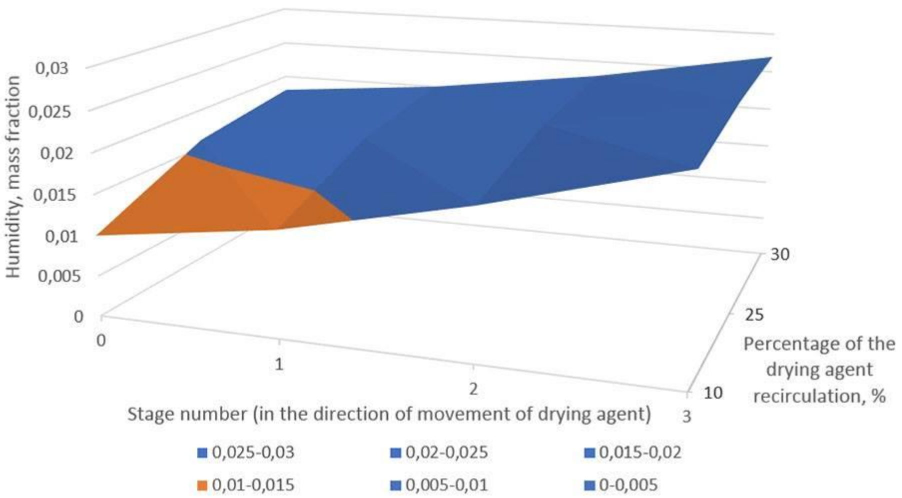

Fig. 5. An influence of the drying agent recirculation method on the change of the moisture content in the drying agent.

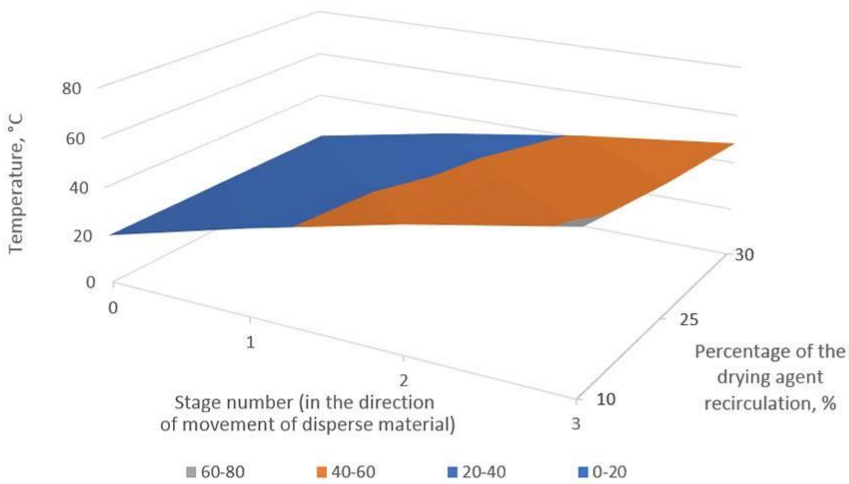

Fig. 6. An influence of the drying agent recirculation method on the temperature change of the disperse material.

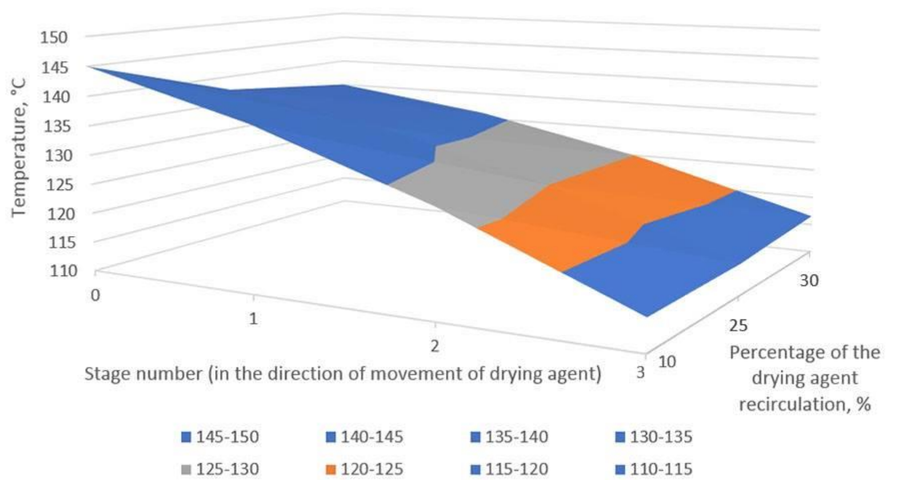

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Fig. 7. An influence of the drying agent recirculation method on the temperature change of the drying agent.

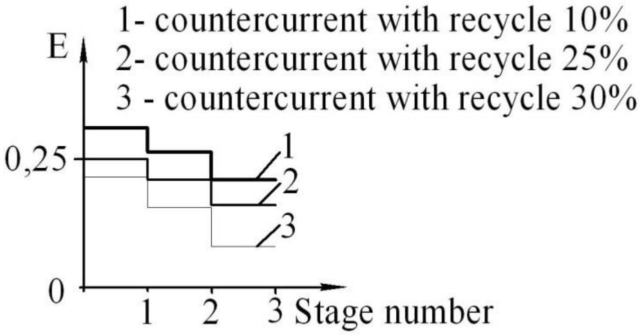

Fig. 8. An influence of the drying agent recirculation method on the drying efficiency (stage number - in the direction of movement of disperse material).

4 Conclusions

The analysis of the computer simulation results proves that the amount of the drying agent, which is repeatedly used as a recirculating flow, has a considerable influence on the moisture of the dried disperse material. Herewith, the quality of the final product is also predetermined by the initial characteristics of the drying agent (temperature and moisture).

The selection of an optimal technological mode of the dryer with the inner space sectioning is a multifactor task, the solution of which considers the peculiarities of the technological process, a constructive design and energy expenditures on heating and transferring the drying agent in the porous medium.

5 Acknowledgments

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References

1. Kudra, T., Mujumdar, A.S.: Advanced Drying Technologies. New York: Marcel Dekker (2002).
2. Mujumdar, A.S.: Handbook of Industrial Drying. Boca Raton: Taylor & Francis Group (2006).
3. Wan Daud, W. R.: Fluidized Bed Dryers – Recent Advances. Advanced Powder Technology, 19 (5), 403-418 (2008).
4. Castro, A.M. Mayorga, E.Y., Moreno, F.L.: Mathematical modelling of convective drying of fruits: A review. Journal of Food Engineering, 223, 152-167 (2018).
5. Artyukhova, N.A., Shandyba, A.B., Artyukhov, A.E.: Energy efficiency assessment of multi-stage convective drying of concentrates and mineral raw materials. Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu, 1, 92-98 (2014).
6. Artyukhov, A., Artyukhova, N.: Utilization of dust and ammonia from exhaust gases: new solutions for dryers with different types of fluidized bed. Journal of Environmental Health Science and Engineering 16(2), 193-204 (2018).

ISSN: 2233 -7857 IJFGCN

7. Atuonwu, J.C., Jin, X., van Straten, G., van Deventer Antonius, H.C, van Boxtel, J.B.: Reducing energy consumption in food drying: Opportunities in desiccant adsorption and other dehumidification strategies. Procedia Food Science, 1, 1799-1805 (2011).
8. Faghri, A., Zhang, Y., Howell, J., Advanced Heat and Mass Transfer. Global Digital Press, (2010).
9. Anderson J-O.: Energy and Resource Efficiency in Convective Drying Systems in the Process Industry (doctoral thesis). Luleå University of Technology, 122 p. (2014).
10. Defraeye, T.: Advanced computational modelling for drying processes – A review. Applied Energy, 131, 323- 344 (2014).
11. Delgado, J.M.P.Q., De Lima, A.G.B.: Drying and Energy Technologies. Advanced Structured Materials, 63 (2016).
12. Van't Land, C. M.: Drying in the Process Industry. John Wiley & Sons, Inc. (2012).
13. Chen, X.D., Putranto, A.: Modelling Drying Processes. A Reaction Engineering Approach. Cambridge University Press (2013).
14. Artyukhova, N.O.: Multistage finish drying of the N_4HNO_3 porous granules as a factor for nanoporous structure quality improvement. Journal of Nano- and Electronic Physics, 10 (3), 03030-1-5 (2018).
15. Artyukhov, A.E., Sklabinskyi, V.I.: Experimental and industrial implementation of porous ammonium nitrate producing process in vortex granulators. Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu, 6, 42-48 (2013).
16. Artyukhov, A.E., Obodiak, V.K., Boiko, P.G., Rossi, P.C.: Computer modeling of hydrodynamic and heat-mass transfer processes in the vortex type granulation devices. CEUR Workshop Proceedings 1844, pp. 33–47 (2017).
17. Artyukhov, A.E., Artyukhova, N.O., Ivaniia, A.V.: Creation of software for constructive calculation of devices with active hydrodynamics. Proceedings of the 14th International Conference on Advanced Trends in Radioelectronics, Telecommunications and Computer Engineering (TCSET 2018), 139-142 (2018).
18. Artyukhova, N.O., Krmela, J.: Nanoporous structure of the ammonium nitrate granules at the final drying: The effect of the dryer operation mode. Journal of Nano- and Electronic Physics 11(4), 04006-1-04006-4 (2019).

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