UDC 661.152.4:66.096.5
DOI: 10.15587/1729-4061.2017.107169

INVESTIGATION OF THE KINETIC LAWS AFFECTING THE ORGANIC SUSPENSION GRANULATION IN THE FLUIDIZED BED

R. Ostroha
PhD*
E-mail: r.ostroga@pohnp.sumdu.edu.ua
M. Yukhymenko
PhD, Associate Professor*
E-mail: yunp@ukr.net
S. Yakushko
PhD, Associate Professor
A. Artyukhov
PhD, Associate Professor*
E-mail: artyukhov@pohnp.sumdu.edu.ua
*Department of Processes and Equipment of Chemical and Petroleum-Refineries
Sumy State University
Rymskoho-Korsakova str., 2, Sumy, Ukraine, 40007

Обґрунтовано доцільність і перспективність виробництва органічних добрив в гранульованому вигляді. Запропоновано в якості органічної суспензії використовувати рідкий курячий послід. Експериментально встановлено температурні режими процесу гранулювання курячого посліду та визначено робочий режим. Отримано критеріальне рівняння для визначення коефіцієнту тепловіддачі від теплового агента до поверхні частинок під час випаровування рідкої фази суспензії

Ключові слова: гранулювання, апарат киплячого шару, органічна суспензія, курячий послід, температурний режим

Обоснована целесообразность и перспективность производства органических удобрений в гранулированном виде. Предложено в качестве органической суспензии использовать жидкий куриный помет. Экспериментально установлены температурные режимы процесса гранулирования куриного помета и определен рабочий режим. Получено критериальное уравнение для определения коэффициента теплоотдачи от теплового агента к поверхности частиц при испарении жидкой фазы суспензии

Ключевые слова: гранулирование, аппарат кипящего слоя, органическая суспензия, куриный помет, температурный режим

1. Introduction

Nowadays environmental problems have become exceptionally acute in the world. Ecological cleanliness, especially in regard to food, is becoming the most urgent issue. It is considered that genetically modified food is greatly harmful to human health [1]. However, the danger of modified food products has not been fully studied yet, and scientists still have not come to the common ground on the issue. At the same time, experts in this area believe that the most harmful food for humans is the one grown with the use of large doses of mineral fertilizers and special growth stimulants. Such vegetables and fruit accumulate various toxic substances, such as lead compounds and other heavy metals, mercury, nitrates, etc. [2].

All mineral fertilizers being manufactured nowadays contain about 50 % of the chemical elements necessary for plants, the rest is ballast substances, which are also absorbed by plants. Growing doses of mineral salts destroy humus, grind the soil structure, making it more dense, cold and inaccessible to air and moisture – all this reduces the natural fertility.

Organic farming is actively developing and applied in the leading countries of the world (USA, France, Germany, China). In 1980, the International Federation of Organic Agriculture Movements (IFOAM) established the Basic Standards for organic production (IBS). They include, first of all, the following requirements: land cultivation must be carried out without the use of any mineral fertilizers at least for three years. It is forbidden to use herbicides, pesticides, insecticides, nitrogen-containing and other chemical fertilizers. At the same time, organic standards have already been introduced at the state level in many European countries, such as Italy, France, Germany. A system for monitoring and compliance with these standards has been created [3].

In 2004, the income of the environmental products market reached $ 16 billion in the United States, representing 2 % of the total volume of food products sales. In Germany and Denmark, the share of such products is 3 %, in France – only 0.5 % [4]. At the beginning of 2009, there were 69 certified organic farms in Ukraine, and the area of agricultural land under organic production was about 239.5 thousand hectares. This enabled Ukraine to take the 16th place in the world among more than 100 countries.

The agricultural potential of Ukraine is very high, which makes it possible to supply organic products to both European and Asian countries. However, it should be born in mind that the domestic market has always been and remains the priority one.

There are many benefits of organic products, ranging from the use of more nutritious food to soil conservation. Organic farming is based on the organic fertilizers and harmful chemicals are not used to increase productivity. Such a strategy prevents depletion of the soil, it has a beneficial effect on water and air nutrition of plants, promotes the development of soil bacteria and microorganisms that help plants to obtain necessary nutrients [5]. About 75 % of organic fertilizers from the introduced amount is mineralized and they participate in plant nutrition, the remaining 25 % – is humified, thereby refilling humus losses after processing crops. Plant residues benefit to restore about 50 % of humus in the coarse soils, in light-textured soils – about 40 % of humus losses; the rest should be restored using organic fertilizers [6].

The most widespread organic fertilizer in Ukraine is animal waste (manure and poultry litter), the constant accumulation of which leads to pollution of the environment. The total volume of livestock waste is about 10 times greater than that of domestic human waste [7]. Livestock enterprises pollute surface water, groundwater and soil since a large number of biogenic elements come into the environment. Therefore, there is a need to develop ways of utilization and rational use of animal waste. Therefore, use of livestock waste in the biochemical cycle contributes, on the one hand, to its utilization, and on the other hand – to expansion of the raw material base for the production of new fertilizers.

Livestock waste looks like a very moist suspension. The fractional composition of solid (suspended) particles varies and depends on the animal species and age, feed diet and pre-treatment of its components. Apparatus with a suspended layer or fluidized bed devices have proved to be universal equipment with high specific power [8, 9]. Therefore, in order to minimize the processing cost of the moist organic substances, it is expedient to use the devices of this type for the granulation purposes. The efficiency of such hydrodynamic system is proved by a number of works devoted to the theoretical grounding of flow motion in apparatuses with intensive hydrodynamic regimes [10] and the study of their ecological safety [11]. Drying process in the mentioned apparatuses using the active hydrodynamic mode, which provides an increase in the relative velocity of the interacting phases, provides the intensification of the process without reducing the economic efficiency of the apparatus. Other advantages of the active hydrodynamic mode are as follows [12, 13]:

– hydrodynamic stability of the process;

– sufficient interaction surface of contacting phases;

– reduction of process energy intensity and metal intensity of devices.

Livestock waste has a natural sticky texture, which results in good adhesion, and therefore no special chemical needs to be added. In case of using liquid chicken manure as an initial suspension, the mechanism of granule formation and enlargement is ambiguous and substantially depends on the temperature mode of the granulation process.

2. Literature review and problem statement

Heat transfer process during granulation in the fluidized bed devices differs from the drying by the fact that a mixture of liquid and small (10–20 microns) organic particles is continuously applied onto the surface of suspended granules. Heat exchange intensity functionally depends on the particle velocity, air temperature, size of the particles and their physical and chemical properties [14, 15].

Interaction nature between droplets of the solution and particles is the most important factor determining the granule growth kinetics. The first attempt to analyze the interaction of granules with droplets of the solution is described in [16]. It is assumed that the solution completely covers the granule. The author calculated evaporation of the solution film under the condition of the combined heat supply: conduction from the granule and convection from the pseudo-liquefying agent. Thus, one obtained the solution for the simplified problem of heat exchange of the sphere with the environment at a constant temperature. The obtained result has a form of the criteria dependence:

$$Nu_{EF} = A \cdot \frac{2 \cdot \lambda_M}{\lambda_G} \cdot \frac{T_R - T_{R+\Delta}}{T_L - T_{R+\Delta}} \cdot Bi + B \cdot Nu_{Nest}, \qquad (1)$$

where λ_M, λ_G is the thermal conductivity of the solid material and gas, respectively; T_R, $T_{R+\Delta}$, T_L is the surface temperature of the granule, film and layer, respectively; Nu_{EF}, Nu_{Nest} are the Nusselt criterion values: effective value and the one calculated by the Nesterenko equation; Bi is the Biot criterion; A, B are empirical constants.

In case where heat conductivity within the particles can not be neglected, the process of heat transfer in the volume of a solid spherical particle, provided that the particle contains a certain amount of moisture, will be written as a system [17]:

$$\begin{cases} \dfrac{\partial t}{\partial \tau} = a_P \cdot \left[\dfrac{\partial^2 t}{\partial r^2} + \dfrac{2}{r} \cdot \dfrac{\partial t}{\partial r} \right] + \dfrac{\varepsilon^* \cdot r_{!}}{c_P} \cdot \dfrac{\partial U}{\partial \tau}, \\ \dfrac{\partial U}{\partial \tau} = k \cdot \left[\dfrac{\partial^2 U}{\partial r^2} + \dfrac{2}{r} \cdot \dfrac{\partial U}{\partial r} \right] + k \cdot \sigma^* \cdot \left(\dfrac{\partial^2 t}{\partial r^2} + \dfrac{2}{r} \cdot \dfrac{\partial t}{\partial r} \right), \end{cases} \qquad (2)$$

where t is the current temperature of the particle, °C; U is the moisture content of the material, kg/kg; t is time, s; a_P is the coefficient of thermal conductivity of solid particles, m^2/s; r is the current radius of the particle, m; ε^* is the criterion of phase transformation; r_C is the specific heat of evaporation, J/kg; c_P is the specific heat of a solid particle, kJ/(kg·K); k is the coefficient of potential conductivity; σ^* is the thermal-gradient coefficient of moisture transfer.

The kinetics of solid spherical particle drying, described by the system of differential equations (2), is a complex problem of heat and mass transfer. A similar problem of drying granules in a vortex suspended layer was solved in [18], where the author obtained a regularity of temperature distribution along a particle radius and described the kinetics of its dewatering. During granulation, liquid phase covers the granule surface with a thin film. Having sufficiently intensive drying process, we assume that moisture evaporates from the surface layer of the granules, and therefore, the criterion of phase transformation, the gradient of moisture content and the change of the moisture content in time within the granule are close to zero.

Thus, the differential equation of mass transfer inside the granule loses its meaning. The differential heat transfer equation in case when the phase transformation criterion tends to zero is converted into a differential equation of non-stationary heat conduction. To solve the latter, it is necessary to determine the values of the established constants, which, in their turn, depend on the Biot criterion value [17]:

$$Bi=\frac{\alpha\cdot R}{\lambda_T}, \qquad (3)$$

where α is the surface coefficient of heat output, W/(m^2·K); R is the particle radius, m; λ_T is the coefficient of heat conductivity, W/(m·K).

To determine the value of heat transfer coefficient, which is a part of equation (3), it is necessary to determine the explicit form of the function $Nu=f(\mathrm{Re},\mathrm{Pr})$. The experimental data are generalized based on the functional dependence between the criteria of heat and hydrodynamic similarities using the well-known equation of convective heat transfer:

$$Nu=A\cdot\mathrm{Re}^n\cdot\mathrm{Pr}^m. \qquad (4)$$

Considering that physical parameters of air will change in the narrow range, we take $Nu\sim\mathrm{Pr}^{0.33}$.

The authors of [15, 19] defined the unknown coefficients A, n, m, in the indicated criteria equation (4) but it is impossible to use them for other materials or drying conditions, as this leads to significant errors in the calculations. In [20], the authors also attempted to determine unknown coefficients from the equation (4) for the case of dehydration of porous ammonium nitrate when covering it with an additional shell. In this case, an optimal operation mode of the equipment is provided, which is characterized by minimal energy consumption to remove a stated amount of moisture. Application of the methods proposed by the authors for determining the coefficients for modeling of the organic suspension granulation is acceptable in the case under consideration. This approach corresponds to modern views on the theoretical description of the dewatering process, which are described in the works devoted to granulation and drying [21, 22].

3. The aim and objectives of the study

The aim of the research is to study the mechanism of granular fertilizers formation by dehydrating organic suspensions in the suspended layer (fluidized bed), as well as determination of the granulation temperature modes. This enables to improve the technology of organic fertilizers production and continuously obtain a multilayered product of specified strength and density.

To achieve this aim, it is necessary to solve the following objectives:

– to study the granulation mechanism in the fluidized bed devices;

– to establish granulation temperature modes for chicken manure suspension in a fluidized bed;

– to offer equipment for the production line of granulated organic fertilizers to cultivate environmentally friendly organic food products.

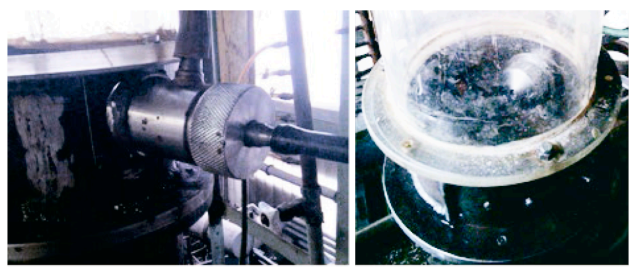
4. Investigation of the organic suspension granulation in a fluidized bed

4. 1. Granule formation mechanisms in a fluidized bed

Granulation process efficiency depends on the mechanism of granule formation, which is determined by the suspension properties, granulation method and equipment in use. Dispersion granulation method is a method wherein using impulses a thin film of a wet substance is applied onto the surface of solid particles in a fluidized bed. Evaporation of liquid takes place due to the heat supplied from the outside. Water or solution evaporates, and the formed layer of dry matter increases the granule diameter. A significant increase in the size of granules takes place after many of such cycles. A zone of suspended granules of 150–200 mm in height is prepared for granulation, which is limited by a gas distribution grid (from below) and the device walls (on the sides). There is a free space on the top since granules come up to a certain height and again fall into a layer.

Spraying the suspension into a fluidized bed is performed using a pneumatic nozzle (Fig. 1), to which compressed air and liquid chicken manure are fed. The compressor maintains pressure within the range of 4–6 atmospheres in the nozzle, which provides the creation of proper irrigation zone in a suspended granular layer.

Compressed air captures the suspension and sprays it into a granule layer, forming a cavity in it, wherein the spray is fed. Consequently, fluidized bed can be divided into two zones: in the first zone drying of granules takes place, and in the second one – the granules are covered with a suspension film.



a *b*

Fig. 1. Placing of the pneumatic nozzle: *a* – view from the outside; *b* – view from the inside

Depending on the process peculiarities, in particular on the granulation mechanism, various parameters affect the size of the granules at different extent or do not affect at all. Therefore, fluidization rate and average stay period of a product in the layer do not affect the size of the granules in a continuous process. However, by heat grinding, as the product stay period in the layer decreases, the formation intensity of new particles goes down. As the fluidization agent velocity decreases, the intensity of granular layer mixing falls. The factors mentioned above reduce the number of heating and cooling cycles, which causes the enlargement of the granule diameter.

Thus, the influence of the process technological parameters on the granulometric composition of the product is reduced to the regulation of the fine fraction amount formed in the layer. It is clear that in order to maintain optimal performance of the granulation process of various substances, different granulation modes are required [23].

Depending on the time of the suspension drop spreading, granulation nature also changes: when heat is fed very quickly, the liquid is removed from the drop, before it has properly covered the surface. As long as the amount of heat fed to the drop goes down, the latter covers the entire granule. In case the heat amount is insufficient to evaporate the suspension drop, the granule remains moist. Obviously, granulation nature depends not only on the rate of moisture removal, but also on the film spreading velocity, which, in its turn, is determined by the properties of the suspension and granule surface.

It should be noted that the conclusions obtained based on the analysis of single droplets and granules interaction do not give a clear explanation of enlargement regularities of granules in the fluidized bed. In the real process, this interaction is complicated by the possibility of simultaneous contact of a granule with several drops, the ingress of some drops of suspension from one granule onto another one upon their direct collision and friction, rotation of the granule, and the like.

As a result of laboratory studies, it was found that in case of using chicken manure as initial suspension, the mechanism of granule growth doesn't always correspond to the uniform or «normal» enlargement as it is considered to be. In other words, it should be noted that the film doesn't always spread on the granule surface in a uniform way [24].

4. 2. Chicken manure properties

Chicken manure is a concentrated organic substance containing the main nutrient elements (Table 1). Except for organic matter, it also includes nitrogen, phosphorus and potassium – macroelements that are so essential for plants. In addition, livestock waste also contains sulfur, magnesium, calcium and lots of trace minerals (manganese, zinc, copper, iron, molybdenum, cobalt, etc.).

Table 1

Chemical composition of chicken manure (% per wet substance)

Water (H_2O)	Nitrogen (N)	Phosphorus (P_2O_5)	Potassium (K_2O)	Calcium (CaO)	Magnesium	Sulphur
53–57	0.7–1.9	1.6–2.0	0.8–1.0	2.4	0.7	0.4

Chicken manure is used as a quick and drastic fertilizer, since it contains easily accessible nutrients for plants. The acidity of chicken manure depends on the age and diet of birds and it is in the range of moderate-alkaline pH (6.5–8.0), which makes it suitable for use in almost all types of soils [6].

4. 3. Temperature modes of the chicken manure granulation

The formation of solid particles of the required size in the granulation process of chicken manure suspension takes place either simultaneously or gradually in a fluidized bed. Depending on the temperature difference between the pre-grid zone and the zone wherein the suspension is fed, temperature modes of granule growth can be distinguished (Fig. 2). Therefore, the processes can be divided as follows: granulation without changing of the particle size in time (Fig. 2, *c*); granulation wherein particles change their sizes in time (Fig. 2, *a*); granulation in which the enlargement of particles and formation of new granulation centers take place (Fig. 2, *b*).

In the course of laboratory studies, temperature under the gas distribution grid was adjusted within the range of 50–100 °C, while air temperature in the granular layer was 40–80 °C. This drop in temperature is explained by the fact that moist suspension is continuously fed into a fluidized bed, which, by evaporation, absorbs heat. Thus, changing the air temperature under the grid, it is possible to regulate the process.

Fig. 3 shows sections of the granules obtained at temperatures of 70–80 °C, corresponding to the shell-type mode with cracks.

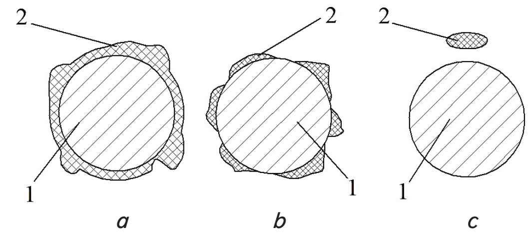
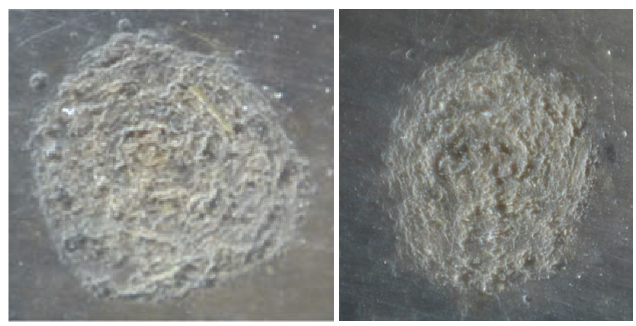


Fig. 2. Growth modes of granules: *a* — shell-type; *b* — shell-type with cracks; *c* — shell-type with the formation of new granulation centers; 1 — organic core; 2 — dehydrated component of the suspension



a *b*

Fig. 3. Sections of the granules (20 times magnification) obtained at a temperature of: *a* — 70 °C; *b* — 80 °C

When studying the sections in Fig. 3, one can see that the granules obtained at a temperature of 70 °C (Fig. 3, *a*) are characterized by a more dense structure. Such structure provides a prolonged effect of the resulting product, since the dynamics of the particle's destruction directly depends on the velocity at which the moisture diffuses inside the granule.

4. 4. Heat transfer of the chicken manure granulation. Summarizing of the results

On the basis of the obtained experimental values, the coefficient of heat transfer from the heat agent to the surface of the particles was calculated during evaporation of the suspension using the heat transfer equation.

Air temperature in the granular layer was measured using a recording potentiometer of KSP-4 type (accuracy of measurement ±0.5 °C). Thermocouple sensors are in the form of thermometric tubes with a diameter of 2 mm and a length of 60 mm, at the ends of which there is a junction of chromel-copel wires with a diameter of 0.1 mm. The thermal capacity of this thermocouple is very small, which allows measurements under conditions of variable temperatures during the experiment. In each experiment, the initial and final temperatures of the drying agent were also measured.

Under experimental conditions, the Biot criterion is within the range of $0.15<Bi<0.3$. According to the recommendations [17], the heat transfer problem is considered to be an external one. This means that the particle temperature is the same within its volume and the entire thermal resistance is concentrated outside the particle.

It should be also borne in mind that the layer temperature was measured with open junctions of thermocouples, which recorded the intermediate value between the temperature of the solid particles and the drying agent. Thus, the calculated values of the heat transfer coefficients are not true, but «effective». Experimental data were presented in accordance with the traditional recommendations in the form of equation (4).

Absolute values of the solid particle velocities are small compared to the drying agent velocity. The relationship between the gas flow rate in the free section of the device and the flow rate in the layer between the particles varies. This takes place both in the intersection and in the height of the layer, and strongly depends on the hydrodynamic mode of the suspended solid phase. Thus, in determining the Reynolds criterion, the average drying agent velocity was taken into account.

To calculate the suspension temperature on the particle surface, the following dependence is obtained:

$$t_{!} = \frac{G_A \cdot c_A \cdot (t_{A1} - t_{A2}) - G_{evap} \cdot r}{G_S \cdot c_S} + t_{S0}, \qquad (5)$$

where G_A is the mass flow rate of air, kg/s; c_A is the heat capacity of air, J/(kg·K); t_{A1} is the air temperature under the gas distribution grid, °C; t_{A2} is the air temperature at the outlet of the device working zone, °C; G_{evap} is the mass flow rate of evaporated moisture (water), kg/s; r is the specific heat of water evaporation, J/kg; G_S is the mass flow rate of the suspension, kg/s; C_S is the heat capacity of the suspension, J/(kg·K); t_{S0} is the initial temperature of the suspension, °C.

Assuming that the temperature on the surface of the solid particles is equal to the temperature of the suspension on their surface, one can build a dependence of the averaged coefficient of heat transfer on the actual velocity of the fluidized air (Fig. 4).

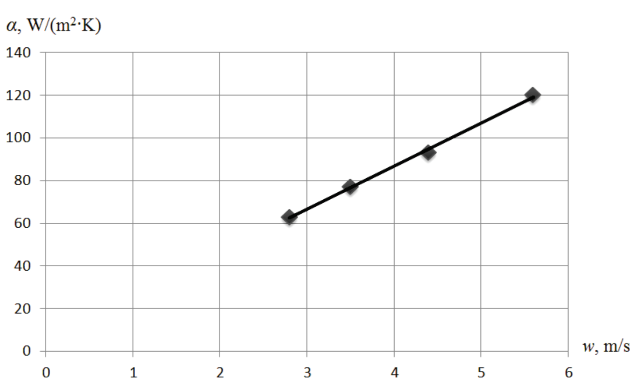


Fig. 4. Dependence of the heat transfer coefficient on the fluidized air velocity under evaporation of the chicken manure suspension from the granule surface

In this case, since physical parameters of air vary in the narrow range, the coefficient m=0.33. Unknown coefficients A, n are determined by presenting the experimental values in the coordinate system with the logarithmic scales.

Having substituted the values of the determined coefficients into equation (4), we obtain:

$$Nu = 0.04 \cdot \mathrm{Re}^{0.85} \cdot \mathrm{Pr}^{0.33}. \qquad (6)$$

Using equation (6), we can calculate the values of the heat transfer coefficients for the chicken manure granulation with an accuracy of ±8.4 %.

5. Development of the equipment for the production line of organic mineral fertilizers

Bird manure contains a large amount of pathogenic and potentially pathogenic microflora and helminth eggs. In addition, unprocessed manure can cause the transmission of infectious and parasitic diseases (brucellosis, tuberculosis, etc.). That is why bird manure is classified as a hazardous material of class III. Therefore, before using it as a fertilizer, it is necessary to prepare (process) it [23].

Based on the theoretical and experimental research results, a unit for the production of granular organic fertilizers has been developed, which takes into account physical and chemical characteristics of the substances in use. The model of such a pilot unit is presented in Fig. 5.

The unit works as follows. First, the initial suspension is ground. Chicken manure goes into the working area of the disk mill. Under the influence of cutting and stretching forces, solid dispersed inclusions of feedstuff, straw, and the like are destructed (ground).

The ground homogeneous substance is decontaminated in the cavitator. Electromagnetic forces cause hydrodynamic oscillations in the processed suspension, which further create vapor-gas bubbles – a phenomenon of cavitation takes place. This phenomenon is accompanied by a sharp local increase in temperature and the creation of shock waves. These processes lead to irreversible biochemical processes in microorganisms at the cellular level.

Further, using a faecal pump, liquid chicken manure is fed into a measuring tank that is equipped with a mixing device, and from there – it goes by gravity into the dispensing pump.

The process of granule formation takes place in the operating chamber of the fluidized bed device. The so-called primer is supplied onto the gas distribution grid. Hot air is delivered through the air-heater under the gas distribution grid, in an amount necessary to provide a stable suspended layer of granules. Doses of organic substance are supplied into the pneumatic nozzle and are sprayed with a compressor. New organic granulation centers are formed directly from the suspension, as well as due to chipping of some particles from the surface of larger granules.

Granules which go into the pneumatic classifier are continuously selected on the grid level. Pneumatic separation process takes place in the pneumatic classifier with the help of a gas blower: small granules (smaller than 2 mm) come back through the pipeline to a fluidized bed for enlargement, and granules of a commercial size (2–5 mm) – are removed from the process and accumulate in the collecting tank.

Cyclone device ensures the ecological functioning of the unit, wherein waste air is cleaned: dust particles accumulate in the collecting tank, and purified air is removed from the unit or production premises.

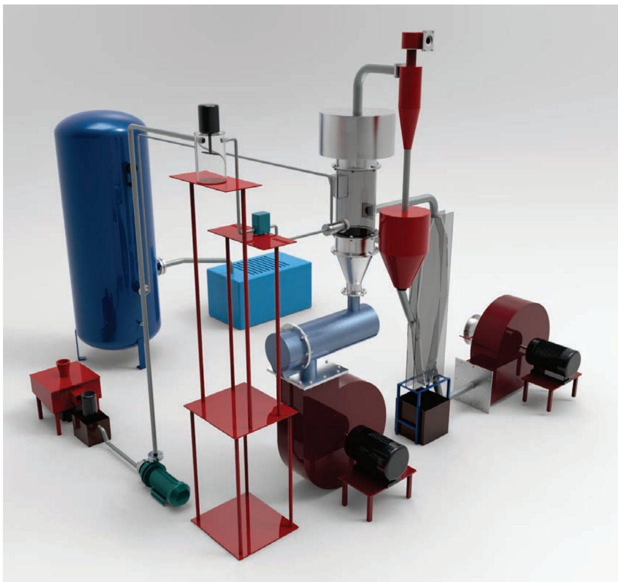


Fig. 5. Design of the pilot unit for organic fertilizers granulation

6. Discussion of the temperature influence on the granulation modes

It has been experimentally determined that if the air temperature in the layer of suspended granules is maintained within 70–80 °C, then two processes take place simultaneously – enlargement of the granules and formation of a small number of particles due to granule chipping. This temperature mode corresponds to the shell-type with cracks (Fig. 2, *b*) and it enables to obtain granular organic fertilizers. This temperature mode also contributes to the continuous operation of the unit for a long time with the constant formation of commercial granules.

At a temperature of the granular layer of 70 °C, suspension drops spread over the surface of the granules and the liquid begins to evaporate vigorously. The newly formed organic surface is cracked and fails to adhere to the granule (Fig. 3, *a*) – this is accompanied by the chipping of organic substance in some places of the granule and the formation of new organic centers of granulation (reverse processes). Though, at the same time there are processes, which are aimed at increasing the size of particles.

With an increase in temperature to 80 °C, suspension fluidization becomes even more intensive – moisture, when evaporating, forms larger cracks on the surface of the granule (Fig. 3, *b*). Due to existing cracks, moisture quickly and easily penetrates into the granule, dissolves and separates organic bonds. Such granules are characterized by lower static strength and they dissolve in the soil much faster.

Therefore, in the set operating temperature range (70–80 °C), lower temperature values should be kept. As a result, we obtain multilayer granules of high density and strength.

7. Conclusions

1. The mechanism of granule formation in a fluidized bed device is studied and the influence of temperature on the granulometric composition of the final product is determined. At a temperature of 70 °C, one can continuously obtain organic granules of high density and strength in a layer of suspended granules.
2. A criteria equation for determining the coefficient of heat transfer from a heat agent to the surface of particles during evaporation of chicken manure suspension is obtained. This equation makes it possible to predict the rate of heat transfer intensity at an increase in the air flow velocity during granulation in a fluidized bed, which allows defining the optimal flow rate of a drying agent.
3. The equipment design of the production line for granular organic fertilizers for cultivation of environmentally friendly food products is proposed. The developed technology takes into account specific properties of wet chicken manure, namely high humidity and stickiness, the presence of viable organisms, weed seeds, etc.

Acknowledgment

This research was conducted under the project «Improving the efficiency of granulators and dryers with active hydrodynamic regimes for obtaining, modification and encapsulation of fertilizers» (state registration number 0116U006812).

References

1. Verma, C. A Review on Impacts of Genetically Modified Food on Human Health [Text] / C. Verma // The Open Nutraceuticals Journal. – 2011. – Vol. 4, Issue 1. – P. 3–11. doi: 10.2174/1876396001104010003
2. Balezentiene, L. Effect of organic and mineral fertilizers and land management on soil enzyme activities [Text] / L. Balezentiene, E. Klimas // Agronomy Research. – 2009. – Vol. 7, Issue 1. – P. 191–197.
3. Morgera, E. Organic agriculture and the law [Text] / E. Morgera, C. B. Caro, G. M. Duran. – Rome: Food and Agriculture Organization of the United Nations, 2012. – 306 p.
4. Panitchpakdi, S. Food safety and environmental requirements in export markets – friend or foe for producers of fruit and vegetables in asian developing countries? [Text] / S. Panitchpakdi. – New York and Geneva: United Nations, 2007. – 120 p.
5. Scialabbe, N. Organic agriculture and climate change [Text] / N. Scialabbe, M. Muller-Lindenlauf // Renewable Agriculture and Food Systems. – 2010. – Vol. 25, Issue 2. – P. 158–169.
6. Arifin, B. The transformation of chicken manure into mineralized organic fertilizer [Text] / B. Arifin, A. Bono, J. Janaun // Journal of Sustainability Science and Management. – 2006. – Vol. 1. – P. 58–63.
7. Pisarenko, V. V. Vidhodi tvarinnictva vplivayut' na dovkillya [Text] / V. V. Pisarenko, P. V. Pisarenko // Fermers'ke gospodarstvo. – 2010. – Issue 20 (484). – P. 14–15.

8. Volchkov, E. P. Investigation of the flow in the vortex chamber with centrifugal fluidizing bed with and without combustion [Text] / E. P. Volchkov, N. A. Dvornikov, V. V. Lukashov, R. Kh. Abdrakhmanov // Thermophysics and Aeromechanics. – 2013. – Vol. 20, Issue 6. – P. 663–668. doi: 10.1134/s0869864313060024
9. Dvornikov, N. A. Investigation of a fluidized bed in a vortex chamber [Text] / N. A. Dvornikov, P. P. Belousov // Journal of Applied Mechanics and Technical Physics. – 2011. – Vol. 52, Issue 2. – P. 206–211. doi: 10.1134/s0021894411020076
10. Artyukhov, A. Theoretical Analysis of Granules Movement Hydrodynamics in the Vortex Granulators of Ammonium Nitrate and Carbamide Production [Text] / A. Artyukhov, V. Sklabinskyi // Chemistry & Chemical Technology. – 2015. – Vol. 9, Issue 2. – P. 175–180. doi: 10.23939/chcht09.02.175
11. Artyukhov, A. E. Experimental and industrial implementation of porous ammonium nitrate producing process in vortex granulators [Text] / A. E. Artyukhov, V. I. Sklabinskyi // Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu. – 2013. – Issue 6. – P. 42–48.
12. Kaewklum, R. Experimental studies on a novel swirling fluidized-bed combustor using an annular spiral air distributor [Text] / R. Kaewklum, V. I. Kuprianov // Fuel. – 2010. – Vol. 89, Issue 1. – P. 43–52. doi: 10.1016/j.fuel.2009.07.027
13. Ashcraft, R. W. Modeling fast biomass pyrolysis in a gas–solid vortex reactor [Text] / R. W. Ashcraft, G. J. Heynderickx, G. B. Marin // Chemical Engineering Journal. – 2012. – Vol. 207-208. – P. 195–208. doi: 10.1016/j.cej.2012.06.048
14. Caiyuan, Y. Heat and mass transfer in process of fluidized bed spray granulation [Text] / Y. Caiyuan, Q. Tao, W. Xizhong // Chinese Journal of Chemical Engineering. – 2004. – Vol. 16, Issue 6. – P. 836–839.
15. Nahurskyi, O. A. Eksperymentalni doslidzhennia teploobminu pid chas kapsuliuvannia dyspersnykh materialiv v zalezhnosti vid shvydkosti teplonosiya [Text] / O. A. Nahurskyi // Voprosy himii i himicheskoy tekhnologii. – 2011. – Issue 3. – P. 105–109.
16. Volkov, V. F. Teplomassoperenos pri granulyacii i sushke rastvorov v psevdoozhizhennom sloe [Text] / V. F. Volkov, I. I. Shishko, L. V. Hohlova // Teplo- i massoperenos. – 1968. – Vol. 5. – P. 248–251.
17. Yukhymenko, M. P. Aparaty zavysloho sharu. Teoretychni osnovy i rozrakhunok [Text] / M. P. Yukhymenko, S. V. Vakal, M. P. Kononenko, A. P. Filonov. – Sumy: Sobor, 2003. – 304 p.
18. Artyukhov, A. E. Kinetics of heating and drying of porous ammonium nitrate granules in the vortex granulator [Text] / A. E. Artyukhov // 2016 International Conference on Nanomaterials: Application & Properties (NAP). – 2016. doi: 10.1109/nap.2016.7757297
19. Barna, I. R. Zovnishniy teplomasoobmin pid chas filtratsiinoho sushinnia syrovynnykh materialiv vyrobnytstva shlakovoho hraviyu [Text] / I. R. Barna, V. M. Atamaniuk // Khimichna promyslovist Ukrainy. – 2012. – Issue 3. – P. 21–27.
20. Artyukhov, A. E. Thermodynamic Conditions for Obtaining 3D Nanostructured Porous Surface Layer on the Granules of Ammonium Nitrate [Text] / A. E. Artyukhov, V. I. Sklabinskyi // Journal of Nano- and Electronic Physics. – 2016. – Vol. 8, Issue 4 (2). – P. 04083-1–04083-5. doi: 10.21272/jnep.8(4(2)).04083
21. Handbook of Pharmaceutical Granulation Technology [Text] / D. Parikh (Ed.). – Informa Healthcare, 2009. – 676 p.
22. Solanki, H. K. Recent advances in granulation technology [Text] / H. K. Solanki, T. Basuri, J. H. Thakkar, C. A. Patel // International Journal of Pharmaceutical Sciences Review and Research. – 2010. – Vol. 5, Issue 3. – P. 48–54.
23. Ostroha, R. Technology of producing granular fertilizers on the organic basis [Text] / R. Ostroha, M. Yukhymenko, Ya. Mikhajlovskiy, A. Litvinenko // Eastern-European Journal of Enterprise Technologies. – 2016. – Vol. 1, Issue 6 (79). – P. 19–26. doi: 10.15587/1729-4061.2016.60314
24. Yukhymenko, M. Hydrodynamic and kinetic processes of the mineral fertilizer granules encapsulating in the multistage device with suspended layer [Text] / M. Yukhymenko, R. Ostroga, A. Artyukhov // Eastern-European Journal of Enterprise Technologies. – 2016. – Vol. 6, Issue 6 (84). – P. 22–28. doi: 10.15587/1729-4061.2016.84179