Improvement of drying process of beer pellet in the fluidized bed apparatus

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Abstract

Introduction. It is appropriate to model and calculate the processes in the fluidized bed apparatus using computer simulation techniques and experimental studies in order to improve the drying process of beer pellet and develop new structures of dryers.

Materials and methods. The process of drying spent grains in the fluidized bed dryer screw. Beer pellet has a thick consistency of rough grinding grain product, a light brown color, sweet flavor and malt smell and it rich in nutrients. Simulation of beer pellet drying was based on the finite element method using the software package Flow Vision and mathematical and statistical methods.

Results and discussion. The mathematical model determining allow the coolant pressure in the drying chamber, to depend on the speed and coolant gas distribution device design and optimum conditions of drying installation. Uniform heating and drying the product in the fluidized state at any point of intersection of the drying chamber of screw dryer is achieved through high-quality distribution of coolant above gas distribution device. The expediency of Reynolds criterion definition was proved using semi-empirical interpolation formula derived by V. Goroshko, L. Rosenbaum, and O. Todes. It allows reducing of marker dimensions of the dryer. The design of screw dryers was improved by established under the perforated gas distribution grid profile that provides directional movement of coolant and coolant levels the pressure along the length of the drying chamber.

Conclusions. Using the results of research for select the mode of drying in the design phase of drying equipment allows improve drying process beer pellet in the dryer.

Introduction

The processing, storage and use of wastes of food production has always been a subject of special attention. A large quantity of wastes, a major part of which is beer pellet, is generated in the breweries during the production of beer. This raw by-product is in great demand for animal and poultry fattening as high calorie protein supplement. The problem of beer pellet is virtually absent in winter. But in the summer, the farmers prefer green fodder. That's why a large amount of beer pellet accumulates in the breweries. The term of its storage is limited.

The issue of the recycling of large amount of beer pellet must be solved because many factories pour it into drains thus deteriorating the ecological situation in Ukraine. The 35,000 tons of beer pellet goes annually to waste at the breweries of the average productivity. There are no effective methods of preserving these products except drying. But drying of beer pellet is not used in Ukraine because of the lack of the appropriate equipment.

The drying of beer pellet to the final moisture of 7 ... 10% ensures a long shelf life, making its production and transportation over long distances cost-effective. The solids residue can be used to obtain a great range of products since it contains about 8% of lipids, 26% of proteins, 58% of carbohydrates, minerals, vitamins and other biologically active substances.

Based on the results of the analysis of drying methods, dryers and drying equipment for beer pellet, and according to the research papers on the study of the drying process, it was found that the improvement of the dryer is needed. The improved dryer must be able to dry the product with minimum energy and material consumption. In accordance with these demands the continuous screw dryers was used.

The effect of design features of the improved screw dryer on the drying process of beer pellet was considered and studied.

The development of new methods of bulk stocks drying, designing of small dryers, dryers and in particular improvement of dryers with fluidized (boiling) bed known for its high efficiency and speed drying, simplicity of construction and operation, quality and flexibility of process control of drying is an actual problem.

Materials and methods

The research material is beer pellet. The pellet formed during filtration congestion as the remainder after separation of the liquid phase - beer wort. Beer pellet has a thick consistency rough grinding grain product, a light brown color, sweet flavor and malt smell. It consists of grain shell, insoluble part of grain. Absolutely dry pellet containing% (wt.), fat – 10; protein – 22; hemicellulose – 35; cellulose – 20; lignin – 10; ashes – 3. Moisture crude pellet is 76...80% (wt.), bulk density of the dried pellet 280...310 kh/m^2. The dry pellet can be used as biogas, ecological fertilizer use in the manufacture of bread, pasta and sausages.

Mathematical models are often used in addition to physical models when designing new types of equipment and improving existing ones. These calculations allow monitoring the process taking place in the equipment with less time and material resources and optimizing it.

Today the regularity of structural effects arising from the interaction of fluidized (boiling) layer and the degree of influence of these effects on the intensification of heat transfer process are not studied in details. To determine the expediency of using the screw dryer for beer pellet drying, it is necessary to conduct further research and mathematical modeling.

An important factor to intensify the drying process is uniform distribution of the drying agent under the grid and uniform distribution of fluidized bed of the product. This factor can be investigated using mathematical modeling. The modeling allows optimize the process and obtain numeric values of the parameters that cannot be measured by using the existing devices.

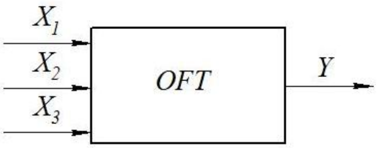

Fig. 1 The general scheme of mathematical and statistical model:
X_1, X_2, X_3 - input variables (factors, regressors),
Y - output variable (review)

To establish the optimal technological mode of drying of beer pellet in the screw dryer, it is necessary to develop a mathematical model of the process by the full factorial experiment (Fig. 1).

To achieve the optimum design of the screw dryer it is needed to investigate the coolant distribution and intensity of the drying agent under the gas distribution grid and the pressure on it.

To do this, it is required to create a computer model of the dryer, run a model and calculation of the drying of beer pellet in the screw dryer.

The procedure of modeling and calculation process includes the following steps:

1. To make a calculation field ("geometry") in CAD and import it into the software package FlowVision.
2. To define the mathematical model.
3. To set the boundary conditions.
4. To set the physical parameters.
5. To set the initial calculation grid.
6. To define the criteria for adaptation of the computational grid.
7. To select the time step of the computational algorithm.
8. To run the calculation.
9. To view the results of the calculation and use the postprocessor capability.

The determination of the Reynolds criteria effects on the calculation of the coolant velocity and as a result, on the size of the dryer (geometry parameters of the grid and the height of the separation space) significantly. Therefore, the choice of the method of Reynolds criteria calculation is one of the main tasks for the developers of the equipment for food enterprises.

The working coolant velocity is determined by the formula:

$$v = \frac{\mathrm{Re} \cdot \mu_n}{d \cdot \rho_n} \tag{1}$$

V.D. Goroshko, L.G. Rosenbaum and O.M. Todes obtained the equation for determining the critical velocity of fluidization for Reynolds criterion using the Ergani equation for pressure drop when gas (liquid) moving through the granular layer:

$$\mathrm{Re}_1 = \frac{Ar}{150 \cdot \frac{1-\varepsilon}{\varepsilon^3} + \sqrt{\frac{1.75}{\varepsilon^3} \cdot Ar}} \tag{2}$$

Also, it should be noted that Rozhdestvensky O.I. received the refined equation:

$$\mathrm{Re}_2 = \frac{Ar}{75 \cdot \frac{1-\varepsilon}{\varepsilon^3} + \sqrt{\left(75 \cdot \frac{1-\varepsilon}{\varepsilon^3}\right)^2 + \frac{1.75}{\varepsilon^3} \cdot Ar}} . \tag{3}$$

Also, the authors Goroshko V.D., Rosenbaum L.G. and Todes A.M. offered the generalized semi-empirical interpolation formula for describing the full range of the fluidized bed existence:

$$\mathrm{Re}_3 = \frac{Ar \cdot \varepsilon^{4.75}}{18 + 0.61 \cdot \sqrt{Ar \cdot \varepsilon^{4.75}}} . \tag{3}$$

where, $Ar = \frac{g \cdot d^3}{v^2} \cdot \frac{\rho_m - \rho_n}{\rho_n}$ – Archimedes criterion; ε – porosity of the layer; g – gravitational acceleration, m/s^2; d – average particle size of the product, m; v – velocity of coolant, m/s; ρ_m, ρ_n – density of the product and coolant (air), kg/m^3; μ_n – viscosity of coolant, Pa·s.

Results and discussion

The drying process of beer pellet in the screw dryer was simulated. The input parameters that affect the pressure (P, MPa) in the drying chamber are: v_p – velocity of the coolant in the holes of the gas distribution grid, m/s; φ - living section of the grid; C - resistance coefficient of the grid.

According to the full factorial experiment the mathematical model of the pressure in the drying chamber was obtained. It is as follows:

$$\begin{aligned} P = 2.286 - 0.379 \cdot \frac{\upsilon_\mathrm{p} - 1.5}{0.5} - 0.614 \cdot \frac{\phi - 0.03}{0.02} - 0.359 \cdot \frac{\upsilon_\mathrm{p} - 1.5}{0.5} \cdot \frac{\phi - 0.03}{0.02} - \\ -0.701 \cdot \frac{\upsilon_\mathrm{p} - 1.5}{0.5} \cdot \frac{C - 0.82}{0.08} - 0.541 \cdot \frac{\phi - 0.03}{0.02} \cdot \frac{C - 0.82}{0.08} + 1.186 \cdot \frac{\upsilon_\mathrm{p} - 1.5}{0.5} \cdot \frac{\phi - 0.03}{0.02} \cdot \frac{C - 0.82}{0.08} \end{aligned} \tag{5}$$

The total error of the experiment is Δ =2,82%.

It should be noted that the construction of the gas distribution grid impacts on the characteristics of the fluidized (boiling) layer in the dryer significantly. The gas distribution grids made in the form of a simple perforated plate, plates with holes closed with caps or cones are widely used.

Fig. 2 shows the effect of the structural characteristics of the gas distribution devices on the fluidized bed characteristics.

As it can be seen from the Fig. 2 the pressure drop is 29% and 41% more when using distributive grids with caps and cones respectively than with perforated grids (porous plates) in the range of critical velocity at the beginning of the fluidization. The decrease of the pressure drop results in the stabilization of fluidized layer, reduction of the hydraulic resistance, the reduction of the costs for creating and maintaining the fluidized bed. It should be also noted that the perforated grids allow obtaining the most uniform layer thus providing the greatest degree of its expansion. They are simple in design, cheap to manufacture and maintain. Therefore, it is recommended to use the perforated grids in the fluidized bed apparatus.

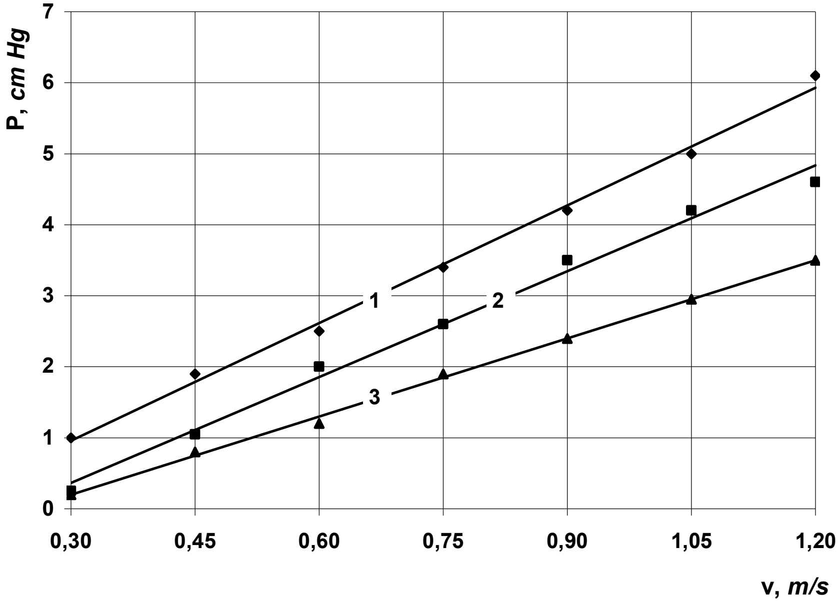

Fig. 2. The variation of the pressure P in a fluidized bed with different distribution devices:
1 - plate with cones; 2- plate with caps; 3 - perforated plate.

After the calculations of the Reynolds criterion dependence on the average particle diameter of the device the characteristic curves were obtained (Fig. 3) for the particle diameter from 0,001 m to 0,005 m according to formulas 2 ... 4 using different methods of calculation.

The plot shows that the use of different methods of the Reynolds number calculation results in obtaining the values that differ from each other. For example, the obtained Reynolds number are very high when using the semi-empirical interpolation formula (4) proposed by Goroshko, Rosenbaum and Todes. But the working and critical velocity of the coolant and the diameter of the device will be less in subsequent calculations than when using the other formulas under the same conditions. The two lower curves obtained from formulas (2, 3) give very similar results that are almost identical to each other.

It can be concluded that the proposed methods (2, 3) allow obtaining very similar results, but very small values of the working velocity of the coolant, which in turn leads to the increase of the dimensions of the device and the reduction of the intensity of the heat and mass transfer.

Therefore, it was recommended to calculate the working velocity and dimensions of the equipment using the semi-empirical interpolation formula (4) proposed by O.M. Todes, Goroshko V.D. and Rosenbaum L.G. According to this formula a big value of the working velocity and, consequently, underestimated dimensions of the device can be obtained.

Thus, the choice of the method of Reynolds number calculation is one of the main tasks for the developers of equipment for food companies.

The improved design of the screw dryer was developed after analyzing the study's results of the drying process of beer pellet. The software package Flow Vision was used to model the coolant motion and vector distribution of its velocity, define the pressure in the drying chamber and temperature distribution, observe the nature of air movement and obtain the experimental data.

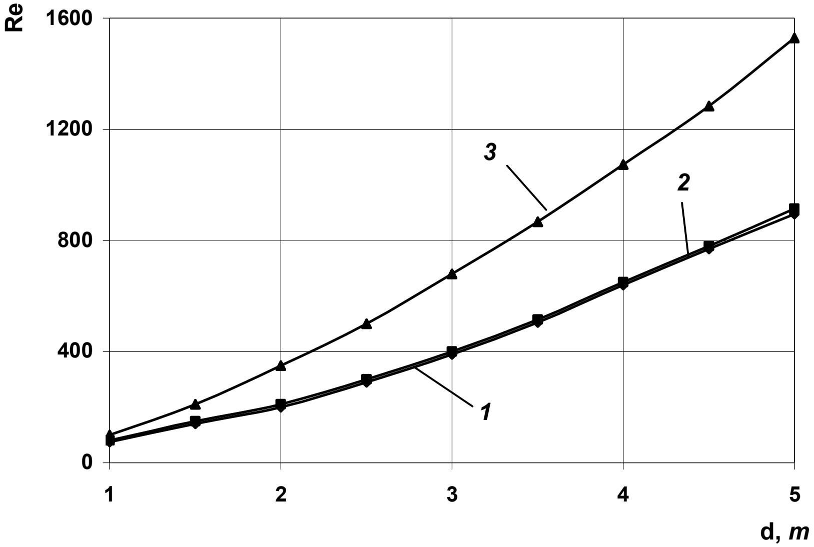

Fig. 3. The Reynolds criterion vs. particle diameter in the apparatus using different methods of calculation:
1 – Re_1; 2 – Re_2; 3 – Re_3

The screw dryer (Fig. 4) performs as follows. The stock is fed into the loading spout 1 of the frame 2 by the feeder while the screw conveyor 3 is rotating and coolant is supplying through the nozzle 5 under the distribution grid 8. The stock is transported from the loading part of the frame 2 to the discharge sleeve 7 by the screw 3. When transporting the stock is stirred intensively and blown by the coolant which creates the fluid (boiling) layer and dries the material. The spent coolant is removed from a frame through the nozzle 4 after rising to the top of the frame 2 above the screw conveyor 3.

The high efficiency of the drying is achieved through the intensive contact of mixing. In addition, the division of the frame 2 by the screw conveyor 3 into the separate sections provides the stability and uniformity of drying. It means that the material cannot come from the loading 1 to unloading 7 disorderly without sequent drying in each section. Thus, the material is evenly dried reaching the unloading section.

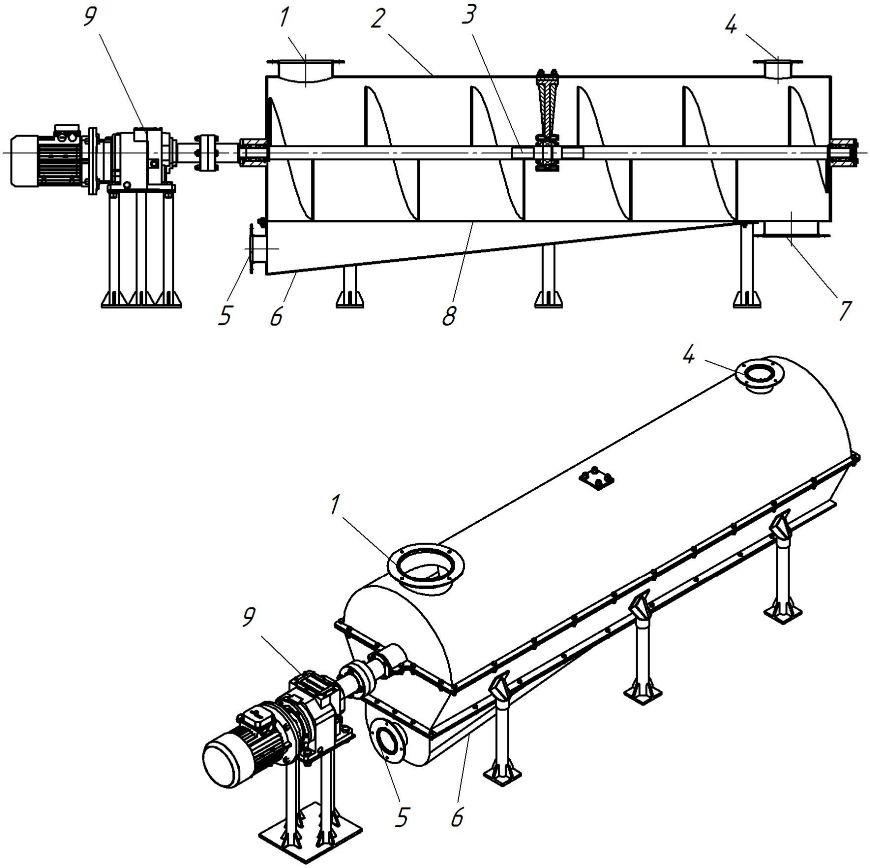

Fig. 4. The screw dryer for the beer pellet drying:
1 – loading spout; 2 - frame; 3 - screw; 4 - nozzle for coolant removing;
5 - nozzle for coolant supplying; 6 - coolant directing profile;
7 - nozzle for discharging the dried product; 8 - gas distribution grid; 9 - screw drive

Conclusions

1. Based on the results of the theoretical and experimental studies the improved design of screw dryer was developed for beer pellet drying. It provides the product drying from the initial moisture content of 80% to the final - 10% with the capacity of 125.4 kg/s.

2. The proposed design of the dryer makes it possible to heat and dry the product uniformly in a fluidized state at any point of the intersection of the drying chamber without disturbance of its properties.

3. The mathematical model was obtained for determining the coolant pressure in the drying chamber. This model allows determining the optimum operating conditions of the dryer.

4. It is recommended to use the semi-empirical interpolation formula by Goroshko V.D., Rosenbaum L.G., Todes O.M. for determining the Reynolds number. This formula will allow reducing the dimensions of the equipment in the subsequent calculations.

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