Heat-and-moisture transfer at the feed meal particles drying and grinding

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Abstract: This article is devoted to the research of heat-and-moisture transfer in operating area of grinding and drying unit (GDU). Preliminarily grinded up and defatted animal wastes (meat and bone tankage) with 39% moisture content were the subject for drying with simultaneous grinding. Feed meal particles of animal origin were the product dried (9-10% moisture) and grinded up (2-3 mm). There were detected the main factors having effect on the air-lift drying process acceleration with the simultaneous impact-splitting grinding. Change in size of the processed material particles was analyzed in 3 sections of operating area of GDU. In the 3rd section of operating area of GDU the particles with the size of 20 mm (60,1%) dominated. In the 2nd section of operating area of GDU the particles with the size of 10 mm (50,1%) dominated. In the 1st section of operating area of GDU the particles with the size of 2,7 mm (90,2%) dominated. Change of temperature and moisture content in the particles of raw product and meal of animal origin has been researched in 3 sections of operating area of GDU. In all 3 sections of operating area of GDU the temperature of the material particles under drying in center is lower than on surface but moisture content is higher. Experiment showed that there was no overheat of minor grinded up particle in the developed GDU thanks to swirling flows appearing at interaction of drying agent with the material under drying.
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1. Introduction

Enhancement of the meat and dairy products quality and growth of its amount significantly depends on development of feed industry aimed at possible to the fullest extent meeting needs of agricultural animals and birds in the nutrient rich and biologically active substances.

Feed meal of animal origin is one of the complete components of feed stuff. In increase of feed meal production the use of all kinds of non-edible materials, wastes and condemned products of the meat processing enterprises and households are of special importance [1]. Dry feeds of animal origin fill the deficiency of the protein substances in vegetal feeds and enhance their accessibility [2-4]. They are characterized by their higher nutrient and feed value [5-8].

Drying processes are widely used in industry and agriculture [9]. In technological flow diagram of the animal feed meal production the drying is the most important process. Drying is a complex engineering process (physical and chemical) which shall provide not only preservation of quality indicators of material but in some cases the enhancement of these indicators [10-11]. Currently the analysis of the drying equipment research [12-14] allows making conclusion that drying process combination with grinding in one unit is the effective instrument of the drying quality enhancement and intensification in production of the feed meal of animal origin [15] because of extension of the phase contact surface, lowering of the moisture transfer diffusion resistance that makes it possible to increase the velocity of heat-and-mass exchange significantly. Besides, drying combination with the grinding enhances the uniformity of the products' thermal processing per factions and allows deep enough dewatering of the material [16].

Drying process combination with grinding is a promising research area. That is the reason for considering the detailed study of the drying process with grinding and improvement of GDU at animal feed meal production as the scientific and technological objective of great current interest.

2. Material and Methods

Targets of research are: phases of the drying process with the grinding in GDU preliminarily grinded up and defatted animal wastes (meat and bone tankage), feed meal of animal origin.

To study the combined process of drying-and-grinding with occurring events of chemical and physical nature, regularities of the heat-and-mass transfer and factors effecting the drying-and-grinding process the technique of system analysis carried out according to the methods of mathematic simulation of engineering processes developed by the school of V.V. Kafarov was applied [17].

Determination of the operation modes of a drying-and-grinding installation (GDI) was executed by means of control and measuring devices: air temperature in different places of experimental installation was measured by chromel-copel thermocouples one of which operated with the possibility to maintain the preset temperature (t_{da}) at the input to GDU. Thermocouples were connected with the potentiometer of TSPU 9313 I type (0-300^{0}C). Adjusting and measuring the velocity of drying agent (V_{da}) delivery was carried out by drying gate and rotary meter. Clearance (δ [delta]) between striking and baffling elements was provided by means of the adjustment of baffling elements. Rate of the striking elements' (n) rotation was changed by means of change wheels. To measure the time a stopwatch with accuracy class of ±1 s was used. To measure the electric energy consumption electric, three-phase, multi-range counter with accuracy of 2,0 was used. To measure the power the kilowatt meter with accuracy class of 1,5% was used.

Evaluation of granulometric or fractional composition of the grinded feed meal particles was executed using the sieve method. Screen analysis was executed by sifting the material samples through a set of standard sieves with meshes the size of which was successively diminishing from top to down. As a result the material was divided into the classes or fractions in each of which the particles differ in their sizes. When sieving some part of material the particle sizes of which are smaller than the mesh sizes pass through the sieve (fraction - d, or through), the other part with more coarse particles remained on the sieve (fraction + d, residue, or tailing). Measurement of the raw product an animal meal was made by means of fine chromel-copel thermocouples. Measurement of the raw product moisture content was made by means of the moisture meter.

Appraisal of the feed meal of animal origin quality [18] was executed using conventional methods: selection of samples and techniques of the animal feed meal testing according to the effective standard [19]; selection and preparation of samples and bacteriological analysis of the feed meal of animal origin according to the effective standard [20].

3. Results

One of the principle directions of increase of the heat-mass exchange processes' effectiveness at the wet materials' drying is the use of high-temperature gas heat-transfer media. Drying in the medium of high temperature heat-transfer agents' media makes it possible to use higher initial temperatures of the heat-transfer agent; high local rates of the drying agent as well as swirling gas flows; combination of techniques and combination of different processes in one unit. In different fields of industry the air-lift drying of disperse materials having the advantage of high intensity at comparatively simple design solution of equipment gets spread-wide application [21].

Hierarch structure of system analysis of the air-lift drying process with simultaneous grinding of the feed meal particles includes five levels. First and second levels of hierarchy of the system analysis of the combined process of drying and grinding at the feed meal production pose the analysis of the subject under drying and grinding on the atomic-molecular level, research of the heat and moisture transfer in the single particle of feed meal, physical-chemical, thermophysical and hygroscopic capacities of the subject under drying and grinding. The third, forth and fifth levels of hierarchy structure of system analysis are considered to be a basis for design solutions at calculation and development of GDU and detection of the main factors effecting the drying process with grinding at the feed meal production. Here, the mechanical processing operation required for grinding and mixing should be understood; work consumed for heating the drying agent delivered to GDU; work necessary to transfer the heat to the GDU space, the finished product with the used agent carrying over from GDU; vortex and thermal agitations carried with the input flows of drying agent and intensive mechanical motion of the blend composition processing subject. These phenomena in the unit space bring the heat and mass flows which form the fields of the heat-and moisture transfer in GDU. Vortex and heat flows in the GDU space have significant effect on the particles' distribution on the unit level, quality of its grinding, i.e. fractional composition of particles, time of the material particles drying in GDU and the finished product efficiency.

The result of system analysis of the air-lift drying process with simultaneous grinding at producing the feed meal of animal origin consists in setting the following main characteristics having significant effect on the drying process intensification:

- extension of the contact area of the dewatered processing subject interaction with a drying agent;
- use of the entire surface of the processing subject for combined action with the drying agent;
- rise of the drying agent temperature non-offensive for quality characteristics of the finished products;
- rise of heat transfer from the drying agent to the processing subject as a result of acceleration of the drying agent moving to GDU within tolerable limits;
- increasing the frequency of mechanical impact effect on the process subject aiming at acceleration of heat-and mass exchange with output of the finished products of standard granulometric composition.

Basic researches were carried out in GDI forming part of the processing line of production of the animal feed meal [22]. In accordance with the figure 1 there were presented the sections (1, 2, 3) of the GDU operating area where on the shaft 4 the series of the rotatable striking elements 5 interchanged with bushing 6. GDU acts as a part of GDI. According to figure 2 the raw product was fed in GDU 1 where it was subject to grinding by series of rotatable striking elements and stationary baffling elements. With the raw product particles' movement the horizontal line of GDU the raw product particles were multiply grinded up under impact of rotatable striking elements. Through other inlet nozzle the hot air pumped by the fan 2 through the electric heating unit 3 was delivered directly to the operating area. This very hot agent captured the air particles and carried them to the cyclone 4 by means of exhaustion created by fan 2. Coarse particles failed to go through the lattice meshes on the output from GDU were deposited to the area of grinding where they were subject to re-grinding. In the cyclone 4 the end product and the used drying agent separation took place. Then the drying agent, over one cycle through the water remover 5 returned to the heating unit 3 where it was heated again and sent for drying. In addition, in air ducting after fan 2 the nozzle 6 with flue damper was installed for additional air delivery. Dried and grinded product through the sluice valve 7 of the cyclone 4 was discharged to the tare 8. In the course of experiments the drying gate 9 and rotary meter 10 were installed on air duct for regulating and measuring the velocity of drying agent delivery. Temperature of air in different place of the experimental installation was measured by chromel-cope thermocouples T_1, T_2, T_3, one of which T_1 operated with the possibility of automatic maintenance of the preset temperature 11 on the output of GDU 1. Thermocouples were connected with the potentiometer 12 of TSPU 9313 I type (0-300^{0}C).

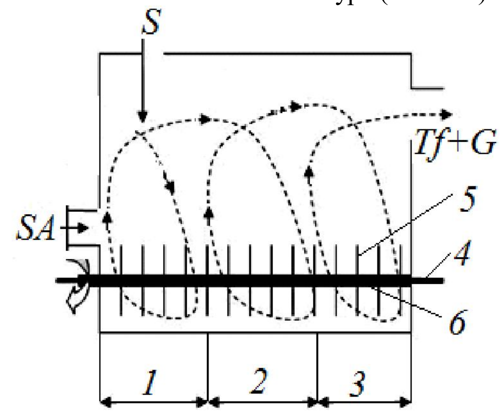

Figure 1 – Operating area of drying-and-grinding unit . A – drying agent; S – raw product; Tf+G – solid phase+gas; 1, 2, 3 – sections of operating areas of the GDU; 4 – shaft; 5 – striking elements; 6 – bushings

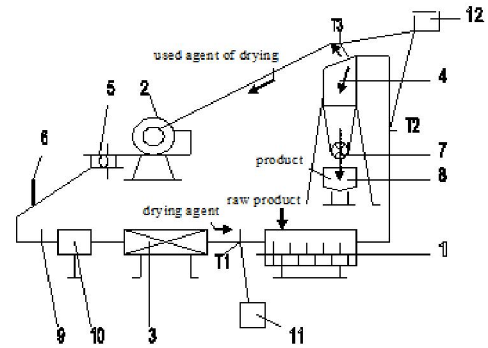

Figure 2 – Diagram of drying and grinding installation. 1 - GDU; 2 - fan; 3 – electric heating unit; 4 - cyclone; 5 –water remover; 6 - nozzle with flue damper for air delivery; 7 – sluice valve; 8- tare; 9-gate; 10-rotary meter; 11 – automatic maintenance of preset temperature; 12 - potentiometer; T_1, T_2, T_3 – thermocouples

Research of the air-lift drying with the simultaneous grinding of the feed meal particles showed high intensity of this technique with provision of the mass transfer increase. Gas flows in the drying chamber are distributed so as the finished product is timely brought out from the area of thermal processing. The product is in the area of high temperatures only for a few seconds that excludes possibility of the initial material overheating and provides preservation of biological value. Technical result of the developed unit consists in the enhancing the quality of the raw product drying and grinding due to uniformity of the temperature and moisture fields' distribution in the unit at separate delivery of the raw product and drying agent that reduces the energy consumption and provides obtaining the high quality, biologically valuable feedstuff. GDU provides uniformity of the grinded material pieces; the grinded particles' removal from the operating area; possibility of the grinding degree regulating; possibility of easy replacement of fast-wearing parts. Original solution of GDU provides maximum surface of the heat-and mass transfer in the area of high temperatures. Active hydrodynamic mode intensifies the drying process. Thanks to close-together arrangement of all subassemblies and parts the general layout is simplified that makes it possible to minimize its dimensions and mass.

4. Discussions

In the process of operation in the inner space of GDU the particles of the processed raw materials of different sizes from x [iks] to x [iks] +dx [iks] the surfaces and sizes of which are changed in the period of time throughout the sections of operating area of GDU. Size of particles of the preliminarily grinded and defatted wastes of animal origin (meat and bone tankage) before loading to GDU constituted 30 mm. Change of sizes of the processed material particles throughout the sections of operating area of GDU is presented in accordance with figure 3. It is seen from the graphic dependencies that grinding leads to the peak of particle sizes change curve displacing in direction to fine fractions. In section 3 of GDU operating area 60,1% of particles had the size of 20 mm, 17,3% of particles had the size of 15 mm, 7% of particles had the size of 10 mm, 12,6% of particles had the size of 25 mm, 3% of particles had the size of 30 mm. In section 2 of GDU operating area 50,1% of particles had the size of 10 mm, 20% of particles had the size of 15 mm, 13,2% of particles had the size of 20 mm, 10% of particles had the size of 5 mm, 6,7% of particles had the size of 2,8 mm. In section 1 of GDU operating area 2,7 мм, 7,2% of particles had the size of 5 mm, 1,4% of particles had the size of 2 mm, 1,2% of particles had the size of 10 mm. The finished product poses the mixture of particles of practically uniform composition (95,4% particles with the size of 2-3 mm; insufficient quantity, i.e. 4,6% of particles with the size of less than 2 mm). Grinding of splitting, breaking and striking action dominates in the unit.

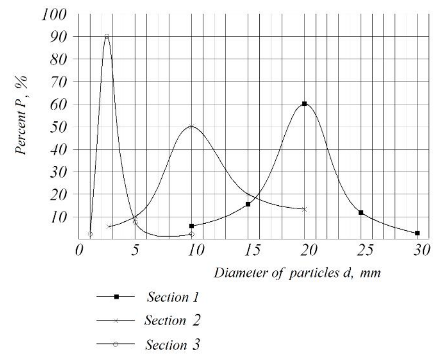

Figure 3 – Change of the material particles' sizes throughout operating area of GDU at V_{da}=3 m/s, n=1500 r/min, δ [delta]=2 mm, t_{da}=160 ^{0}C

According to figures 4 and 5 the curves characterizing the change of the air environment and moisture content of the particles under drying by the unit height in the third section of GDU operating area are presented.

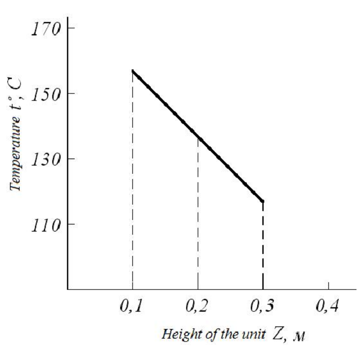

Figure 4 – Air environment temperature changing in height of the unit in the third section of GDU operating area at V_{da}=18 m/s, n=1500 r/min, δ [delta]=2 mm, t_{da} =160^{0}C

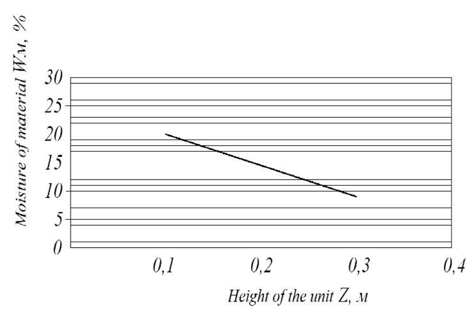

Figure 5 – Dried particles moisture changing in height of the unit in the third section of GDU operating area at V_{da} =18 m/s, n=1500 r/min, δ [delta]=2 mm, t_{da} =160^{0}C

The minimum temperature (116,5^{0}C) of air environment is observed in the upper part of GDU, a higher temperature (158,3^{0}C) is observed in the lower part of GDU where the direct delivery of hot air is executed. The maximum moisture content of the particles under drying (19,8%) is observed in the lower part of GDU, and the lowest moisture content of the particles under drying (9%) is observed in the upper part of GDU where the outlet mesh for output of the dried and grinded particles of the finished feed meal of animal origin is located.

In accordance with figure 6 the curves of the moisture and temperature distribution in the particles of raw product and meal of animal origin dried and grinded in the grinding and drying unit are presented. In the period of heating the particles of raw products and meal of animal origin material redistribution of moisture in all space occurs, moisture content gradient from center to periphery and maximum of moisture content in the center of dewatered material occur.

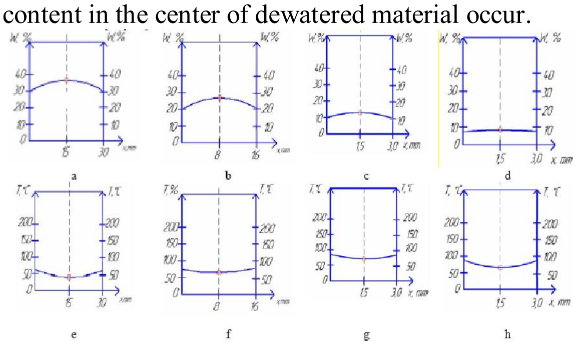

Figure 6 – Moisture content and temperature distribution in the particles of the raw product and feed meal of animal origin at V_{da}=18 m/s, n=1500 r/min, δ [delta]=2 mm, t_{da}=160^{0}C; W – moisture content of material, %; T – temperature of material, ^{0}C; x – dimension of particles of the raw product and feed meal of animal origin, mm: a – moisture distribution in the particle of material being in the section 1 of operating area of GDU; b – moisture distribution in the particle of material being in the section 2 of operating area of GDU; c – moisture distribution in the particle of material being in the section 3 of operating area of GDU; d - moisture distribution in the particle of the finished feed meal of animal origin; e – temperature distribution in the particle of material being in the section 1 of operating area of GDU; f - temperature distribution in the particle of material being in the section 2 of operating area of GDU; g - temperature distribution in the particle of material being in the section 3 of operating area of GDU; h - temperature distribution in the particle of the finished feed meal of animal origin come out from GDU.

It is obviously seen haw the curves of moisture content distribution are symmetrized. Temperature of the dried material particle in the center is lower than on the surface, and moisture content is higher. Moisture content in the particles of preliminarily grinded and defatted wastes of animal origin (meat and bone tankage) before loading to GDU constituted 39%. Here as a result of evaporation and heating the material the successive dewatering and heating of the dried particles. Dewatering and heating occur as a result of two oppositely directed flows of moisture: due to moisture conductivity – from middle to surface of the material, and as a result of heat-and moisture conductivity – from surface to middle. In this case the process intensity provides the increase of productivity, diminishing the specific heat consumption and metal consumption of the equipment and reducing expenses for its operation at high quality of the manufactured product.

5. Conclusion

So, the experiments have shown that lack of the fine grinded particles overheating in the developed GDU due to drying agent interaction with the material under air-lift drying, and uniformity of the thermal fields and the drying agent direct delivery to operating area of the unit make it possible to decrease heating temperature that correspondingly facilitates reducing the energy consumption by 3,5%.

6. Findings

Diminishing the particles' size by means of grinding extended the total surface for the particles drying. Formation of new surface led to extension of the pores' size that, in its turn, facilitates the mass exchange between the drying subject and drying agent. Technical and economic profit from the GDU use is undoubtedly high. Potential gains from the feedstuff products obtained from the wastes of meat industry [23-24], may exceed the incoms from the meat foofstuff sale.

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