Досліджено концентрації, фізичні властивості і хімічний склад пилу, що утворюється в обладнанні підприємств галузі хлібопродуктів залежно від характеру виробництва і місця його утворення.

Встановлено, що концентрація пилу змінюється від 130 до 640 г/м³. Фізичні властивості пилу наступні: насипна щільність – 350–570 кг/м³, мінеральні речовини – 0,6–7,8 %, дисперсія з d=50 мкм від 3,8 до 18, а з d=5 мкм від 1,7 до 6,3. Хімічний склад пилу, у % на суху речовину: крохмаль – (17–75), білок – (0,2–18), пентозани – (2,0–6,2), жир – (0,2–3,6), цукор – (1,7–58), целюлоза – (0,8–48).

Отримані результати свідчать про те, що максимальні значення концентрацій пилу мають місце у відділеннях підготовки зерна до переробки (обладнання для обробки поверхні зерна підготовчого відділення млина – 640 г/м³). Мінімальне значення – у підсилосних ковеєрах елеватора – 130 г/м³.

Зольність змінюється від 0,6 % (борошняний пил у вальцах розмельного відділення млина) до 7,8 % (зерновий пил у підсилосних конвеєрах елеватора).

Насипна щільність змінюється від 350 кг/м³ у змішувачі комбікормового заводу до 570 кг/м³ – у підсилосних конвеєрах елеватора.

Найбільш дисперсні частинки утворюються у вальцах розмельного відділення млина, а найменш дисперсні – у обладнанні елеватора.

Хімічний склад пилу, у % на суху речовину: крохмаль – (17–75), білок –(0,2–18), пентозани – (2,0–6,2), жир – (0,2–3,6), цукор – (1,7–58), целюлоза –(0,8–48).

Хімічний склад представлений вуглеводами, білками, жирами, мінеральними речовинами, що дає підстави вирішувати питання його утилізації.

Отримані данні корисні для вирішення питання утилізації зернового і борошняного пилу.Зерновий і борошняний пил є цінним вторинним ресурсом, легко відновлювальним, дешевим і доступним джерелом сировини для кормових добавок після відповідної обробки.

З урахуванням обсягів, фізичних властивостей і хімічного склад пилу підприємств галузі хлібопродуктів розроблено схему переробки його і рідких відходів мокрого методу підготовки зерна до переробки, у вуглеводно-білкові кормові добавки у вигляді біомаси до комбікормів.

Розроблено схему переробки відходів, висівок і зернового пилу у кормові гранули з метою кращого їх зберігання і використання у комбікормовому виробництві.

Ефективність процесу переробки і використання відходів підприємством галузі хлібопродуктів представили комплексом інтегральних критеріїв, які характеризують кількісну та якісну сторони цього процесу. Комплексний інтегральний критерій ефективності технологічного процесу дозволить виявляти для конкретного підприємства резерви для удосконалення. Інтегральний критерій ефективності технологічного процесу Кеф. повинен наближатися до його максимального значення (Кеф.→1). Чим менше його значення для даного підприємства, тим існують більші резерви для удосконалення процесу

Ключові слова: галузь хлібопродуктів, обладнання, зерновий пил, фізичні властивості пилу, хімічний склад, утилізація, схема, кормові добавки, кормові гранули, критерії ефективності

UDC 658.382.2
DOI: 10.15587/1729-4061.2018.141013

STUDYING THE EMISSIONS FROM ENTERPRISES IN THE BREAD-MAKING INDUSTRY IN ORDER TO USE THEM AS ADDITIVES TO ANIMAL FEED PRODUCTS

M. Zatserkliannyi
PhD, Associate Professor
Department of Thermal Physics and Applied Ecology*
E-mail: doczmm@ukr.net

V. Gogunskii
Doctor of Technical Sciences, Professor**
E-mail: vgog@i.ua

Yu. Semenyuk
Doctor of Technical Sciences, Associate Professor
Department of Thermal Physics and Applied Ecology*
E-mail: suv1902@ukr.net

T. Stolevich
PhD, Associate Professor**
E-mail: tbstolevich@ukr.net

Yu. Zheliba
PhD, Associate Professor
Department of refrigeration and air conditioning*
E-mail: yuriy@nio-holod.com.ua

*Odessa National Academy of Food Technologies
Kanatna str., 112, Odessa, Ukraine, 65039
**Department of Systems Management Life Safety
Odessa National Polytechnic University
Shevchenka ave., 1, Odessa, Ukraine, 65044

1. Introduction

Until recently, the successful development of industry was inevitably linked to the large emissions of polluting substances into the environment. The leading countries in terms of industrial production occupy the first place in terms of emission of pollutant substances into the atmosphere. Those include China, the United States, Germany, Japan, Russia, India and Brazil [1].

As a result of economic activity in such sectors as energy generation, transportation, agriculture, processing industry and recycling of waste, the air is polluted with substances or chemical compounds that form in the atmosphere secondary pollution through their participation in various chemical reactions [2].

A significant contribution to the volume of emissions of pollutant substances into the atmospheric air is produced by the food industry. Many technological processes at these enterprises are accompanied by the formation and discharge of dust into the environment (dairy, meat-processing, oil-fat, grain-processing enterprises) [3]. Thus, in bread-making, all technological processes are accompanied by a significant release of dust, which is one of the main pollutants at enterprises [4]. Dust pollutes the environment, exerts a negative impact on staff [5], causes a premature failure of technological equipment, and it is highly explosive and dangerous in terms of fire [6]. The discharge of dust at enterprises in the bread-making industry leads to the loss of part of the raw materials and finished products [7, 8].

The drawback of studies into the processes of formation and discharge of dust at enterprises in the bread-making industry is the consideration of processes related only to the discharge of dust into industrial premises and the environment.

Given the above, in order to substantiate the possibility of using dust emissions as additives to animal feed, it is a relevant task to undertake a new study into determining the concentration and properties of dust formed in the equipment, depending on the character of production, the place of its creation, raw materials, the type of technological equipment and its technical condition.

Such information is required to assess the prospects for utilizing the waste as an easily recovered, cheap and affordable source of raw materials for animal feed after appropriate treatment.

2. Literature review and problem statement

One of the tasks that has gained in recent years more importance in terms of environment and sectoral significance is to reduce losses in the production technology of bulk products by improving the emission purification from dust-like fractions, which would make it possible, in turn, to protect the air environment. However, when substantiating the application of different technologies, researchers do not consider factors in the loss of bulk materials due to dust formation and the negative impact of dust on the environment [9].

Solving a given task is complicated by the lack of full information about the physical-chemical parameters of dusty air emissions.

The most detailed study of certain physical-chemical and structural-mechanical properties of dust-like food products, as well as the operational parameters of dusty air emissions, was reported in paper [10].

Articles [11, 12] showed that the air-grain dust is a complex mixture of fragments of organic material from grains, plus a mineral substance from soil. Particularly high levels were found at terminals where grain was imported or exported, as well as in the processes of drying. However, the bread-making industry has achieved significant success in improving the control over air dust due to the more efficient processes, enhanced automation, and better attention to product quality. The authors estimated the average levels of dust volume in premises and argue that the highest levels are registered during operations to clean grain, loading and packaging, and reach 10 mg/dm^3, far exceeding the maximum permissible value.

Paper [13] investigated experimentally the composition of dust at an animal feed enterprise. It is shown that at the feed mills the sources of dust release are all technological processes in the preparation of ingredients, as well as processes to form animal feed. The composition of dust depends on the type of raw materials and finished products, the technical condition of processing equipment, as well as equipment for transportation and storage of finished products. However, the quantitative characteristics of the dust formed and released at feed mills are missing.

In addition, the authors of work [13] received an interesting result: the dust-like waste of grain processing enterprises improve the quality of animal feed.

Enterprises in a given industry belong to the "conditionally waste-free" production [14]. This primarily refers to the flour-grinding and groats enterprises, where the waste is mainly used when obtaining certain products [14]. At the same time, the waste from grain accepting enterprises and grain elevators is almost not used, and even if used, the degree of their utilization is insignificant [15].

Paper [16] shows that the waste from the bread-making industry is used without proper processing to feed farm animals. That accounts for up to 70 % of waste while the grain dust is not used at all.

Study [17] experimentally proved the possibility in principle to accumulate the yeast biomass as a result of fermentation of different kinds of aspiration dust waste (Fig. 1). However, the process lasts long and its implementation requires improvement.

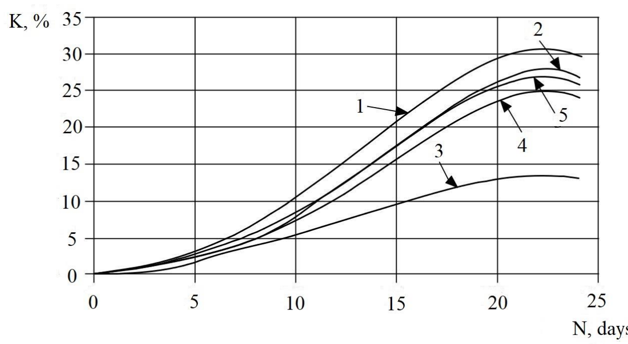

Fig. 1. Accumulation of the yeast biomass during fermentation: 1 – wheat dust from the milling unit of the mill; 2 – grain dust from the preparatory unit of the mill; 3 – grain dust from a grain elevator; 4 – dust of mixed type; 5 – control experiment of the mixed-type dust

Thus, as demonstrated by the considered studies, at present there are no data regarding the qualitative and quantitative composition of dust depending on the place of its formation, raw materials, the type of technological equipment and its technical condition.

The procedure for the use of aspiration waste as an additional resource source has not been fully defined. There are no developed technologies for the comprehensive use of waste, bran, and grain dust.

Still to be determined are the criteria that would make it possible to evaluate the effectiveness of the process of recycling all types of waste from the bread-making industry into secondary products.

All the above allows us to assert that it is expedient to undertake further research with special attention to be given to determining the composition, physical-chemical properties of dust at enterprises in the bread-making industry depending on the place of its formation, raw materials, the type of technological equipment. It is required to improve the scope of application of aspiration waste and to construct an integral criterion to estimate the efficiency of waste processing.

3. The aim and objectives of the study

The aim of this study is to examine the possibility to develop a technology for using at enterprises of the bread-making industry the dust that forms in the technological equipment at enterprises of the bread-making industry, based on taking into consideration its real volume, concentration and properties.

To accomplish the aim, the following tasks have been set:

– to investigate the concentration, physical properties, and chemical composition of the dust that forms in the equipment at enterprises of the bread-making industry depending on the character of production and the place of its formation;

– to construct a scheme for processing the grain dust and liquid waste formed when using the wet method of grain preparation to processing, into the carbohydrate-protein feed additives, in the form of biomass, to animal feed;

– to develop a scheme for processing the waste, bran, and grain dust into feed granules;

– to construct the integral criteria of efficiency of waste processing into feed products.

4. Objects, materials, research methods to study the concentration and properties of dust at enterprises of the bread-making industry

4. 1. Objects of research and examined materials

We have chosen to study such objects as the following acting enterprises from the State food grain corporation of Ukraine (SFGCU): a branch of PAT “SFGCU”, “Odessa grain terminal”, a branch of PAT “SFGCU”, “Odessa cereal plant”, DP “Kulindorovsky grain products plant” in Odesa oblast, which have grain elevators (enterprises for accepting, processing, storage and discharge of grain), enterprises that produce flour, cereals and animal feed.

Production processes at the enterprises involve accepting, drying, moving, processing, storing and discharging grain, processing it into flour and groats, and at the feed mills – involve the processing of waste from food production [6].

All technological processes at these enterprises are accompanied by the release of different pollutants into production premises – excessive heat, moisture, harmful gases, dust.

However, the main pollutants that are released at enterprises of the industry are the waste and dust from grain and raw materials, intermediate products and finished products, which is the subject of our research.

Because these enterprises (during all technological operations) generate waste and dust from grain and raw materials, intermediate products and finished products, we examined the equipment that forms and releases grain, flour or feed dust.

These include at a grain elevator: heads of bucket elevators, elevator scale, silo-top conveyors and distributing devices, separators, silo-bottom conveyors, receivers from automobile vehicles, receivers from railroad transport, devices for the discharge of grain to water transport).

These include at the mill in a preparatory unit: heads of bucket elevators, scales, separators, triers, equipment for the surface treatment of grain, shoes of bucket elevators.

These include at the mill in a grinding unit: rollers, sieves, equipment for enrichment.

These include at feed mills: separators for grain cleaning, scales, a mixer, a conveyor belt for bran with yeast additives.

4. 2. Methods to study the concentration and properties of dust

We have chosen as the basic indicators for the properties of dust (waste) that were determined during experiments: the concentration of dust, physical properties of dust and its chemical composition.

The values of these characteristics helped assess the character of danger and harm from dust (waste) for humans, equipment, its fire safety and explosiveness, as well as the possibility to dispose of it.

The chosen research methods are the acting international standards:

– we investigated the concentration of pollutant substances using the portable dust concentration meter VKP-1 from the Ukrainian Research Institute of Transport Medicine (made in Ukraine); the dust content in the industrial environment was determined using a gravimetric (weight) method; in line with ISO 9096:2003 “Stationary source emissions – Manual determination of mass concentration of particulate matter”;

– bulk (volumetric) density was determined in line with ISO 7971-2:1995 “Describes a routine method for the determination of bulk density, called “mass per hectoliter” of cereals (wheat, barley, oats and rye), utilizing a 1-liter measuring”;

– we determined the ash content in line with ISO 2171:2009 “Cereals, pulses and by-products at feed mills Determination of ash yield by incineration”;

– we determined dispersity in line with ISO 7708:2006 “Air quality. Particle size fraction definitions for health-related sampling”;

– we determined the protein content in line with ISO 5983-1:2005 “Feeds, mixed feeds and raw material. Determination of mass fraction of nitrogen and calculation of mass fraction of crude protein. Kjeldahl method”;

– we determined the content of fat in line with ISO 7302:2003 “Cereals and cereal products — Determination of total fat content”;

– we determined the content of starch in line with ISO 15914:2016 “Animal feeding stuffs. Enzymatic determination of total starch content”.

5. Results of studying the characteristics of dust and the ways to use it

The averaged concentrations of dust that is formed in the equipment depending on the character of production and a place of sampling at the examined enterprises are given in Table 1.

Table 1

Dust concentration

Production site, place of sampling	Dust concentration, g/m^3
Grain elevator	
Heads of bucket elevators	280
Scale	240
Silo-top conveyors and distributing devices	290
Separators	240
Silo-bottom conveyors	130
Receivers from automobile vehicles	540
Receivers from railroad transport	380
Discharge devices for water transport	480
Mill (preparatory unit)	
Heads of bucket elevators	260
Scale	180
Separators	320
Triers	210
Equipment for grain surface treatment	640
Shoes of bucket elevators	260
Mill (grinding unit)	
Rollers	260
Sieves	380
Equipment for enrichment	370
Feed mill	
Separators for grain cleaning	490
Scale	320
Mixer	470
Conveyor belt with yeast additives	530

Table 2 gives the averaged values of the physical properties (ash content, bulk density and dispersion) of dust that forms in the equipment at the examined enterprises.

Table 3 gives the chemical composition (starch, protein, pentosanes, fat, sugar, cellulose) of dust formed in the equipment at the examined enterprises.

Table 3

Chemical composition of dust, % per dry matter

Production site, nature of dust	Starch	Protein	Pentosanes	Fat	Sugar	Cellulose
Grain elevator (grain dust)	17–23	0.2–0.5	4.0–6.2	0.2–0.4	2.6–5.8	32–44
Mill preparatory unit (grain dust)	19–24	0.3–0.5	3.8–4.5	0.2–0.3	1.8–5.3	31–45
Mill grinding unit (grain dust)	71–75	11–18	2.0–3.5	0.9–1.9	1.7–2.9	0.8–1.4
Feed mill	36–43	12–19	4.2–5.9	2.3–3.6	3.4–4.6	43–48

Our study has shown that dust forms inside the shells during operation of transportation and technological equipment.

Based on the observed concentrations, physical properties and chemical composition of the dust that forms at enterprises of the bread-making industry, we constructed a scheme of microbiological processing of grain dust and liquid waste generated when using the wet method of grain preparation grain for processing.

Table 2

Physical properties of dust

Production site, place of sampling	Ash content, %	Bulk density, kg/m^3	Dispersion	
			d=50 μm	d=5 μm
Grain elevator (grain dust)				
Heads of bucket elevators	6.0	540	10	2.0
Scale	5.4	540	10	2.0
Silo-top conveyors and distributing devices	5.3	540	10	2.0
Silo-top conveyors and distributing devices	4.8	520	8	1.8
Separators	6.5	530	12	2.0
Silo-bottom conveyors	7.8	570	20	4.0
Receivers from automobile vehicles	7.3	560	18	3.0
Receivers from railroad transport	4.6	520	8	1.8
Mill (preparatory unit, grain dust)				
Heads of bucket elevators	3.8	530	10	2.0
Scale	3.6	530	10	2.0
Separators	2.8	520	8	2.2
Triers	2.9	520	8	2.2
Equipment for grain surface treatment	2.5	490	12	3.0
Shoes of bucket elevators	3.8	530	10	2.0
Mill (grinding unit, grain dust)				
Rollers	0.6	510	4	1.7
Sieves	0.7	460	3.8	2.4
Equipment for enrichment	0.8	490	4.6	2.8
Feed mill				
Separators for grain cleaning	5.9	380	12	6.3
Scale	5.8	360	18	4.6
Mixer	5.7	350	18	5.8
Conveyor belt with yeast additives	5.8	370	16	4.9

The scheme for processing dust and liquid waste with the application of biological reactors is shown in Fig. 2.

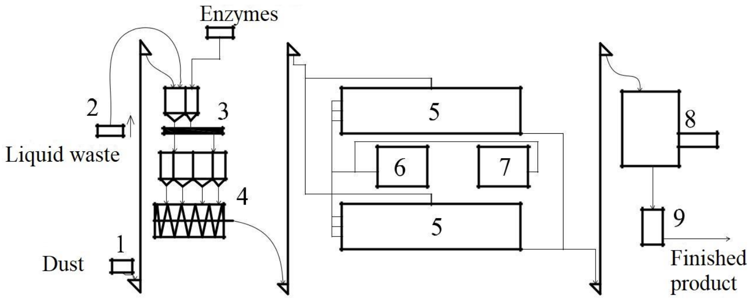

Fig. 2. Scheme of processing dust and liquid waste: 1 — acceptance of dust-like waste; 2 — acceptance of liquid waste; 3 — hoppers with screw dispensers; 4 — screw mixer; 5 — biological reactors; 6 — turbo blowers; 7 — steam generator; 8 — dryer; 9 — chopper

We have developed a scheme to process the waste, bran and grain dust into feed granules (Fig. 3).

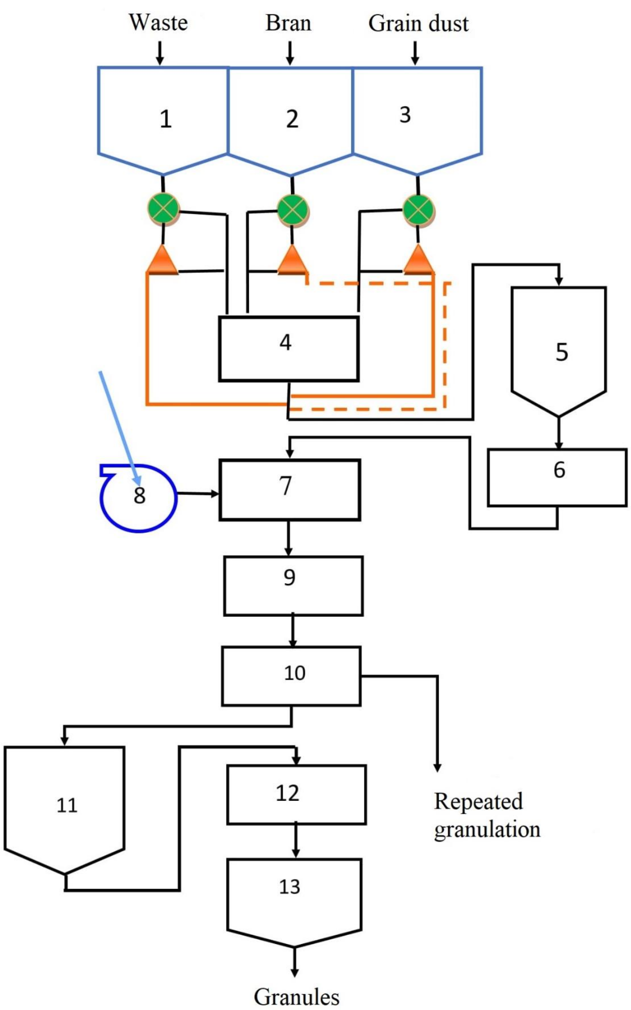

Fig. 3. Scheme for processing the waste, bran and grain dust: 1 — bunker for storing grain waste; 2 — bunker-collector for bran; 3 — bunker-collector for dust-like waste; 4 — crusher; 5 — operational bunker; 6 — press granulator; 7 — cooling column; 8 — fan; 9 — bunker-collector for granules; 10 —vibratory table; 11 — hopper over the scale; 12 — automated scale; 13 — silo storage of granules

The efficiency of processing the waste into products at an enterprise in the bread-making industry can be represented in the form of a complex of integral criteria that characterize the quantitative and qualitative aspects of this process.

We shall represent criteria in the form of costs.

The integral estimate for the efficiency of applying the advanced technologies by an enterprise in the bread-making industry when processing the waste into different types of products, and the efficiency of processing in terms of the requirements of environmental management, can be characterized using a criterion of the waste-free technological process.

$$K_{\text{wastelessness}} = 1 - \left(\sum V_{oj} \cdot H_{cj} \,/\, \sum V_{ci} \cdot H_i\right), \quad (1)$$

where V_{oj} is the volume of the j-th type of waste; H_{cj} is the cost of raw materials used to form the j-th type of waste; V_{ci} is the volume of the i-th component of the product; H_{ci} is the cost per unit of raw material of the i-th component of the product.

An enterprise should seek to maximize the potential of processing the waste into products. This can be estimated by maximizing the criterion of waste-free technological process:

$$K_{\text{wastelessness}} = \max\left\{1 - \left(\left(\sum V_{oj} \cdot H_{cj}\right) / \sum\left(V_{cj} \cdot H_{cj}\right)\right)\right\}. \quad (2)$$

To estimate the degree at which an enterprise obtains, from grain waste, the products (both technical and food), we shall introduce a criterion of the raw material processing depth:

$$K_{\text{depth}} = 1 - \left(\left(\sum V_{oj} \cdot H_{cj}\right) / \left(\sum V_{nl} \cdot H_{nl}\right)\right), \quad (3)$$

where V_{nl} is the volume of the j-th product; H_{nl} is the unit cost of the j-th product.

The coefficient of the processing depth should also approach its maximum value.

$$K_{\text{depth}} = \max\left\{1 - \left(\left(\sum V_{oj} \cdot H_{cj}\right) / \left(\sum V_{nl} \cdot H_{nl}\right)\right)\right\}. \quad (4)$$

Because products obtained from waste must be "environmentally friendly", there is a need for the introduction of the criterion of ecological compatibility of the technological process, which characterizes how dangerous for the environment the proposed technology is, which is applied by an enterprise for waste disposal.

This criterion will take the form

$$K_{\text{eco-friendly}} = 1 - \left(\left(\sum V_{oj} \cdot H_{yj}\right) / \left(\sum V_{ni} \cdot H_{ni}\right)\right), \quad (5)$$

where H_{yj} is the cost of disposal a single unit of the j-th waste.

The optimal criterion of ecological compatibility must also approach its maximum value

$$K_{\text{eco-friendly}} = \max\left\{1 - \left(\left(\sum V_{oj} \cdot H_{yj}\right) / \left(\sum V_{ni} \cdot H_{ni}\right)\right)\right\}. \quad (6)$$

These criteria are part of the integral criterion of the effectiveness of the technological process that characterizes the excellence and completeness of processes that are implemented at a particular enterprise in the bread-making industry from the point of view of economic efficiency and environmental safety of the manufactured products

$$K_{\text{efficiency}} = K_{\text{wastelessness}} \cdot K_{\text{depth}} \cdot K_{\text{eco-friendly}} \to 1. \quad (7)$$

The set of such criteria makes it possible to evaluate existing technologies taking into consideration not only economic, but also environmental component.

To illustrate the efficiency of processing the waste into products at an enterprise in the bread-making industry, we submit calculations for DP "Kulindorovsky grain products plant".

Performance indicators for the enterprise:

– grain processing productivity – 500 t/day;

– volume of waste per 1 ton of grain – 25 kg;

– amount of grain dust per 1 ton of grain – 1 kg;

– amount of bran per 1 ton of grain – 40 kg;

– the cost of a ton of wheat grain – USD 429.61;

– the cost of disposal of 1 ton of waste – USD 540.15.

At present, out of all secondary resources, the enterprise utilizes only bran.

Criterion of the waste-free technological process for the enterprise is:

$$K_{\text{wastelessness.}}=1-[(0.026\cdot 429.61)/(0.066\cdot 429.61)]=0.93.$$

The maximally possible criterion of the waste-free technological process $K_{\text{wastelessness}}$ can only be reached under condition of the complete processing of waste into products.

Criterion of raw materials processing depth:

$$K_{\text{depth.}}=1-[(0.066\cdot 429.61)/(0.934\cdot 429.61)]=0.60.$$

The optimal coefficient of raw materials processing depth K_{depth} is determined by the perfection of the technological process. The coefficient can approach its maximum value $K_{\text{depth.}}=1$ Technology requires improvement.

Criterion of ecological compatibility of the technological process:

$$K_{\text{eco-friendly.}}=1-[(0.066\cdot 540.15)/(0.934\cdot 429.61)]=0.91.$$

It is quite high for the enterprise.

The optimal criterion of ecological compatibility can approach its maximum value under condition of bringing down the cost to dispose of waste.

Integral criterion of the technological process efficiency,

$$K_{\text{efficiency.}}=0.93\cdot 0.60\cdot 0.91=0.51.$$

Because the integral criterion of technological process efficiency $K_{\text{efficiency}}$ should approach its maximum value ($K_{\text{efficiency}}\to 1$), there are reserves for improvement at a given enterprise.

6. Discussion of results of studying the characteristics of dust and the ways to utilize it

The merit of the research we conducted is that it included an important stage – acquiring data about comprehensive characteristics: concentration, physical properties and chemical composition of dust formed in the equipment at enterprises of the bread-making industry.

Owing to that, the results obtained have an advantage over similar studies that considered only the processes of dust release into industrial premises and the environment [4, 5].

While earlier studies only stated that the emission of dust at enterprises of the bread-making industry was linked to the loss of part of raw materials and finished products [7, 8], the research we report here substantiates the possibility of utilizing dust emissions.

However, this task requires conducting a broader research.

The advantage of our study is that the efficiency of processing the dust waste into products at an enterprise of the bread-making industry is represented by a set of integral criteria that characterize the quantitative and qualitative aspects of this process. The comprehensive integral criterion for the technological process efficiency would make it possible to identify reserves for improvement at a specific enterprise.

The noted drawbacks could be eliminated by undertaking additional research to cover more enterprises in the industry with respect to raw materials and finished products, the type of technological equipment and its technical condition.

In addition, we plan to develop the technology to dispose of the waste generated at enterprises of the bread-making industry.

7. Conclusions

1. Our research has established that the concentration, physical properties and chemical composition of the dust that forms in the equipment at enterprises of the bread-making industry depend on the character of production and the place of its formation. Dust concentration varies from 130 to 640 g/m^3. The physical properties of dust are as follows: apparent density – 350–570 kg/m^3, mineral substances – 0.6–7.8 %, variance at d=50 μm is from 3.8 to 18, and at d=5 μm, from 1.7 to 6.3. The chemical composition of dust, % per dry matter: starch – (17–75), protein – (0.2–18), pentosanes – (2.0–6.2), fat – (0.2–3.6), sugar – (1.7–58), cellulose – (0.8–48).

2. We have developed a scheme for processing the grain dust and liquid waste generated when using the wet method of grain preparation into feed additives in the form of the biomass to animal feed. It includes the equipment for dosing, mixing the dust and liquid waste, biological reactors, a dryer to dry biomass, and a shredder. The inclusion of biological reactors in the scheme ensures the fundamental possibility for implementing a hydrolysis decomposition of all organic components of dust (carbohydrates, fats, proteins), which makes it possible to obtain a product in the form of the yeast biomass.

3. The scheme was developed to utilize waste, bran, and grain dust to obtain feed granules. It includes the equipment for grinding the grain waste and bran, dosing, a mixer to mix them with dust-like waste, pressing and cooling the feed granules, and a vibratory table to separate sub-standard granules.

The inclusion of the press-granulator to the scheme ensures the fundamental possibility to form granules through steaming and gelatinization of carbohydrates that are included in the composition of grain and wheat dust, grain waste and bran.

4. The effectiveness of processing grain dust, waste, and bran into animal feed products at an enterprise in the bread-making industry is proposed to be represented via a set of criteria that demonstrate:

– the waste-free technological process;
– raw materials processing depth;
– environmental compatibility of technological process.

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