Greening by grain waste recycling in cereal industry

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Abstract. Ecologically feasible ways of cereal wastes recycling are considered and their comparative analysis is carried out. The description of granulation methods for waste is especially investigated and the most effective technical solution for the studied elevator is proposed. Grain wastes of category III are not suitable for cattle and poultry feeding, therefore, they are stored in the territories adjacent to a grain processing enterprise for a certain time, and then they are taken to the landfill or burnt. The wastes include the wastes from the process of grain cleaning with the grain content of not more than 2% and with the presence of straw particles - buckwheat, oats, barley and suction husks, scouring black dust. The given waste type of elevator has properties that make it possible to use them as a secondary material resource. Their recycling acquires an important environmental, economic and energy-saving significance. In Western Europe, the use of solid fuels - granules and briquettes - has become widespread. The main types of plant-growing subcomplex wastes in agro-industrial complex, which are used for solid, liquid or gaseous biofuels production, are straw, cut and husk of cereals crops, peeling, corn shell, flax bonfire and other plant materials.

1 Introduction

It is necessary to consider effective and environmentally friendly ways of waste disposal concerning their annual amount in cereal production. The existing methods for cereal waste recycling involve their thermal or chemical treatment [1, 2].

For example, for an elevator complex that carries out a cycle of operations from grain receiving, drying, cleaning, storing to producing wheat flour, bran and animal feed, the secondary use of wastes makes it possible to use it as a secondary material resource. Their return to the material cycle acquires an important environmental, economic and energy-saving value.

According to the Information and Technical Handbook of the Best Available Technologies dated 12/20/2017, annually, at the elevator, when processing cereals (wheat, oats, rye, barley, buckwheat) into cereals/ flour, the waste up to 75% from the mass of processed raw materials is generated [1]. This includes plant waste such as husk, bran, peeling, shell, substandard grain, solids, etc. (V hazard class [3]). According to the Federal Law “On Production and Consumption Wastes” dated 24/06/1998, No. 89-FL, V hazard class waste can be stored at the enterprise for 11 months [4]. However, despite the low hazard class, grain waste poses a biological and fire hazard, and also, under certain conditions, grain dust is explosive.

The goal of the study is formed based on the need to utilize large amounts of waste from the grain industry. It is production greening at the elevator by installing efficient equipment for the secondary use of grain waste.

To achieve the goal, it is necessary to perform a number of tasks:
- the analysis of the technological cycle of the elevator complex;
- the identification of qualitative characteristics and calculation of quantitative parameters of grain waste generated during the operation of the elevator;
- the selection of alternative technologies for their disposal with technical, economic and environmental parameters.

2 Materials, methods and objects of research

A large amount of waste is generated practically at every stage of grain cleaning [5, 6, 7].

Cereal wastes are divided into 4 categories. The way of their further use is determined depending on the category.

I category:
a) waste containing 30-50% of grain - production of feed, ethanol;
b) waste containing 10-30% of grain - production of animal feed or for technical purposes

Category II waste can contain grains from 2 to 10%. It is used for technical purposes and less often for feed production.

Category III is the waste of grain cleaning process with a grain content of not more than 2% and with the presence of straw particles, husk, millet, buckwheat, oats and barley, suction, scouring black dust. This category is used for technical purposes or it is burnt.

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The fourth category includes grain dust, most often sent for elimination by burning [2].

Despite the great demand from farms and private households, only about 40% of all cereal waste (category I and II waste) is used for feeding. Accordingly, category III waste (husk and peeling) is stored at the enterprise. Therefore, this category of waste is the object of the further research.

Based on the data presented on the website of the Ministry of Agriculture of the Russian Federation, we calculate the average crop weight delivered to an elevator located in one of the regions of the Republic of Tatarstan [8]. Thanks to "Collection of specific indicators on production waste and its consumption" dated 7/03/1999 [9, 25], we have an average value of husk formation during grain processing - 26%. It will not be difficult to determine the total amount of grain waste of category III formation per one year of grain harvest [27]. The calculation results are presented in table 1.

Table 1. The dependence of the waste amount on the grain amount.

Culture	Sown area, ha	Crop yield, tons / ha	Crop, tons	Waste, tons
winter wheat	10,500	4.37	45,885.0	11930.1
winter rye	700		3059.0	795.3
spring wheat	400		1748.0	454.5
spring oats	100		437.0	113.6
spring barley	600		2622.0	681.7
TOTAL	12300		53751.0	13975.3

The presented results prove that about 14 thousand tons of valuable grain waste, which is not used in animal feeding, is annually produced at the elevator while grain processing. Accordingly, an environmentally sound and efficient method for its secondary use is needed.

One of the possible ways of some grain waste recycling is to use it as fertilizers, since soil application serves as the most valuable energy and nutrient material for soil biota [10, 11]. Unfortunately, not all waste can be directly used as fertilizer material. Besides, such grain waste using has little economic benefit for the enterprise.

In Western Europe, solid fuels - fuel briquettes and pellets (granular fuel) - have become widespread [28-32]. The calorific value of such material made from vegetable waste is comparable to coal, and its relative cheapness allows it to be used as industrial energy sources and for domestic purposes [2, 11, 19].

Let us consider the technological characteristics of the equipment for a briquetting line and granulation line from various manufacturers and compare them (table. 2.) [12-19].

Table 2. Equipment technological parameters.

Indexes	Recycling Methods					
Technology	Briquetting			Granulation		
	1	2	3	4	5	6
Equipment	EcoTronex (Pini&Kay)	Flagma (Nestro)	Taiga (Ruf)	Scarabey	GranMaster	SKJ 350
Place of production	Rep. Moldova	Kirov	Novosibirsk	Shchekino	Khimki	China
Type of used grain waste	Sunflower husk, straw	Wood waste, husk	Sunflower husk, straw	Vegetable waste, straw	Straw, sunflower husk	Peat, grain waste
Purchase + installation of equipment, thousand rubles	3650	5588	1050	4950	3130	3800
Product size, mm	50 x 50 x 30	60 x 40 x 40	60 x 40 x 40	10 x 30	8 x 50	6 x 20
Calorific value, Kcal/kg	3500-4500	3500	3572	4400	4500	3500
Average equipment productivity, kg/h	250	400	350	450	350	600
Waste using, m3/hour	350	560	490	630	490	840
Power consumption, kW/h	35-55	110	26,4	69	33	30
Overall dimensions, m	5 x 8 x 4	15 x 10 x 6	3 x 1 x 2	6 x 3 x 5	3 x 1.5 x 2	2 x 1 x 1.5
Consumed Electric power kW/month	7200	17600	4224	11040	5280	4800

According to table 1, "PINI&KAY" briquettes, manufactured on EcoTronex equipment, have the highest calorific value. "PINI&KAY" means mechanical processing of raw materials with screw presses, which combine high pressure and heat treatment. Due to this, the lignin contained in the raw material becomes a kind of glue that forms the briquette into a dense and durable product, which allows it to be transported over long distances. For comparison, "RUF" and "NESTRO" fuel briquettes are not resistant to moisture or long-term transportation. They should be located close to the place of production [12-14, 25].

Among the pelletizing equipment, the leader in calorific value is the line from the company LLC "Gran Master" - the largest producer of animal feed and pellets production equipments [16]. Also, the analysis of the table shows that the granulation lines, despite their small size, have greater productivity compared to briquetting lines.

The machine productivity Q_{tr}, kg/h, required for the elevator under consideration, is determined by the amount of raw materials processed during the maximum machine loads [20]. The calculation is carried out according to the formula:

$$Q_{tr}=G/t_y, \quad (1)$$

where G is the number of products or items processed for a certain period of time, kg; t_y - the conditional time of the machine operation, h.

$$t_y=T*\eta_y, \quad (2)$$

where T is the duration of the workshop operation, h; η_y - conditional utilization of the machine operation, (0.3-0.5).

Taking into consideration the elevator under study, T is equal to 16 hours a day, respectively ty - 8 hours. The amount of grain waste processed during this time daily (G) must be at least 4 tons, since otherwise, for 10 working months of the elevator, the waste generated during the season cannot be completely recycled. Consequently, the line for solid fuel production from grain waste with high productivity is needed in case of a large volume of husk.

Based on the calculation, a machine is selected that has a capacity close to the required one. Out of the considered options for briquetting and granulating lines, the equipment numbered 2, 4, and 6 have the highest productivity. We will determine the actual operating time of these lines (t_f, h):

$$t_f=G/Q, \quad (3)$$

where Q is the productivity received from the machine, kg / h.

$t_{f\,(2)}$=4000/400=10 hours;

$t_{f\,(4)}$= 4000/450=9 hours;

$t_{f\,(6)}$=4000/600=6.5 hours.

So, to select the best technology for the recycling of grain waste, we will compare the equipment from the manufacturers "Flagma" [13], "Scarabey" [15] and "SKJ" [17].

3 Results and discussion

The economic benefit of the implemented measures (R, million rubles/year) is the sum of the prevented economic damage from the elevator waste per year (ΔU, thousand rubles/year) and the annual increase in income (additional income) from the subsequent improvement of the production activities of the enterprise (ΔD, thousand rubles/year) [21, 22]:

$$R=\Delta U+\Delta D, \quad (4)$$

Analyzing the calculated results of the economic efficiency of measures in grain waste recycling, we can draw the following conclusions:

- the equipment with number 6 from the Chinese manufacturer has the lowest unit production cost. The pellets production needs less economic resources in comparison with other lines presented;
- the calculation of the main criterion shows that granulated fuel production lines are more suitable than briquetting lines for the elevator under study. The calculations reflect the project's economic feasibility;
- the introduction of waste recycling at the enterprise prevents economic damage of more than 8 million per year [18, 26];
- the feasibility of the project's implementing is proved by the calculation of absolute economic efficiency. This indicator should be more than 1. To build a briquetting line on the elevator under study is not coherent from an economic point of view. It is again proved when calculating the production's profitability [22 - 24];
- according to the calculations, the investments in the imported "SKJ5500" equipment are more efficient, respectively, the payback period for equipment with number 6 is less.

4 Conclusions

So, by analyzing the technological cycle of the elevator complex, the main stages of the formation of grain waste of category III are identified. The calculation of the quantitative parameters of grain waste showed that the largest amount of waste is formed during the processing of winter wheat, and the total amount of grain waste formation of category III per year is about 14 thousand tons at the elevator under study.

The comparison of various types of equipment gives us the right to make the choice in favor of "SKARABEY" pellet production line. The selection of an alternative disposal technology is made taking into consideration technical, economic and environmental parameters. The calculations show that the greatest economic efficiency is the investment in the proposed line.

Thus, the production of fuel pellets can significantly reduce the amount of waste caused by the enterprise's operation and reduce the burden on the environment. Pellets can be used in conventional boilers or furnaces. The fact that while burning no emissions other than carbon monoxide and nitric oxide are formed is a beneficial one. The ash after briquettes burning can be used as fertilizer. Accordingly, the introduced technology can be considered to be practically waste-free. It presents the feasibility of introducing the line of grain waste granulation at the elevator for production greening.

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