

Economic effectiveness of the aspiration systems in fiber by-products recycling technology

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Abstract. The paper presents a wide variety of by-products with low bulk density and high dispersibility and ways of their utilization. To obtain compacted products from this type of materials the preliminary micro-granulation stage is necessary, which can be done by the roller compactor. It is suggested to carry out the process of powdered by-products compaction in the vibration-centrifugal granulator, which includes a device for pre-compacting and three drums, where sequentially conducted processes of pellet formation in waterfall-cascade mode, classification by vibration and compacting of the surface layer in the drum with toroid-shape chambers. The manufacturing technology of compacted products made of paper, cardboard and other fiber-type material wastes includes a waste shredding stage in the shredder and rotary crusher that follows by a pneumatic conveying of the gas-dispersion mix into the cyclone unit for dispersed phase settling. Therefore, the mentioned-above method of its compacting is acceptable for the collection in cyclone grinded particles. To increase the settling efficiency of the fiber type by-products it is worthwhile pre-compacting it, which follows with the microgranules obtaining by the pneumomechanical method in the airflow. The paper presents the technology of the granulated materials obtaining by pulp-and-paper waste recycling. It demonstrates the economic effectiveness of the introduction into the aspiration system of technological complex the pneumomechanical device for dispersed mix agglomeration using subquality products and bonding additives.

Keywords: fiber by-product, microgranulation, pneumomechanical device, cyclone unit, baghouse filter, degree of purification.

1. Introduction

Complex processing of raw material resources is an important issue in the modern industry, including recycling of different wastes resulting in commercial product output for different purposes. Industrial plant waste can be liquid or solid in the form of dispersed materials with different physical-and-mechanical and physical-and-chemical properties. There is a special group that consists of fiber waste from the woodworking and pulp-and-paper industries, agriculture, paper, and cardboard waste, etc. Due to their low actual and bulk density, their branched structure and high «volatility» it is difficult to catch them in the aspiration system plants of technological complexes.

The objective of this paper. Reveal economic effectiveness of the technological complex operation for paper and cardboard waste recycling using the pneumomechanical device in the aspiration



system to microgranulate grinded material for the purpose of the settling degree increase in the cyclone unit. The use of the subquality products in pneumomechanical agglomeration as a center of pellet formation decreases material losses and increases complex operation effectiveness as a whole.

2. The by-product characteristics

One of the promising ways of the powdered by-products recycling is a manufacture of compacted products using granulation, extrusion or compaction methods.

It should be noted that the manufacture of the compacted products is a topical issue in many technological processes, for example, glasswork industry [1-3], metal and mining industry [4], because granules contain the most of useful properties in less possible volume. Compacting of the dispersed mixes and materials is being done both at the intermediate and also at the final stages of the market-ready products manufacture, which allow material dusting reduction, simplify storage conditions, transportation, etc.

However, some by-products have low bulk density (less than 200 kg/m^3), high dispersity. The granulated product manufacture from such batches requires a step-by-step process of formation, which must start from the compacting stage to create centers for granulation [5]. Such materials include powdered waste from the production of expanded perlite, vermiculite, lime, and the other construction industry waste. The obtained granules can be used in the heat-insulating mixes, lime-potash and organomineral fertilizers [6]. The process of the powdered by-products compacting is suggested to perform in the developed by us vibration-centrifugal granulator (RF patent #2412753). The vibration-centrifugal granulator includes a pre-compacting device and three drums, where in a sequential manner conducted processes of pellet formation in waterfall-cascade mode, classification by vibration and compacting of the surface layer in the drum with toroid-shape chambers (Figure 1).

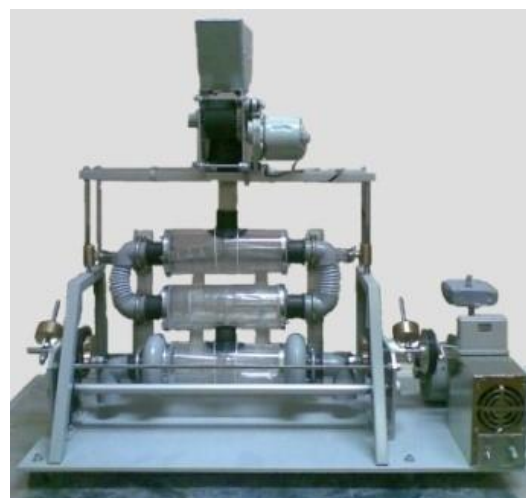
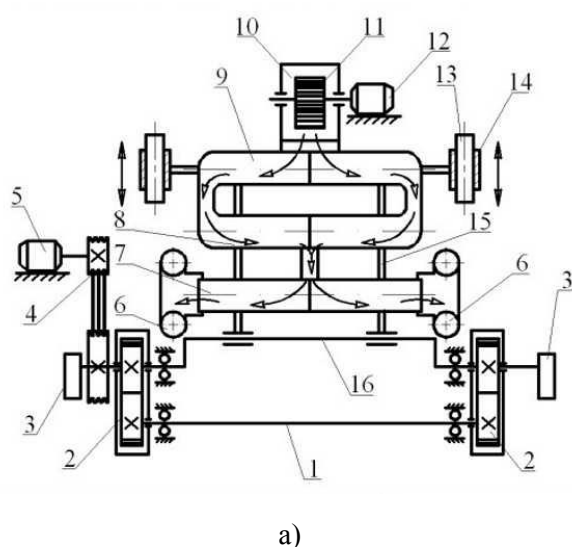


Figure 1. Kinematic diagram (a), overall view of the vibration-centrifugal granulator (b): 1 - connecting shaft; 2 - pair of gears; 3 - counterbalances; 4 - V-belt drive; 5 - electric motor of the main drive; 6 - toroid-shape chambers; 7, 8, 9 - drums for material granulation; 10 - vibrating chute; 11 - elastic compacting roll for microgranulation; 12 - electric motor of the device for material pre-compacting and microgranulating; 13 - guide columns; 14 - sliders; 15 - moving frame; 16 - eccentric shaft.

It should be noted that the process of the polydisperse mix formation is very complicated, technology and equipment choice of which depends on the physicomechanical and physicochemical characteristics of the moulded mixes, and their rheological properties. Theoretical and practical research of these processes can be found in many Russian and foreign scientific papers [7-12].

The fiber by-products represent a special group of wastes. The by-products that have a fiber structure consists of woodworking industry waste (in the form of sawdust, wood shavings), construction industry (manufacture of the heat-insulating materials, asbestos cement products); processing industry (textile production, fiberglass); agriculture industry (plant production, agro-industrial complex) and so on. Most of the fiber by-product materials (FBM) is a pulp-and-paper waste (PPW). Cellulose is the most common polymer on Earth, which plays a very important role in carbon circulation in nature. However, the pulp-and-paper industry waste annual increase and environmental contamination by it require search for new PPW recycling methods.

Figure 2 presents the fiber by-products classification and methods of their recycling.

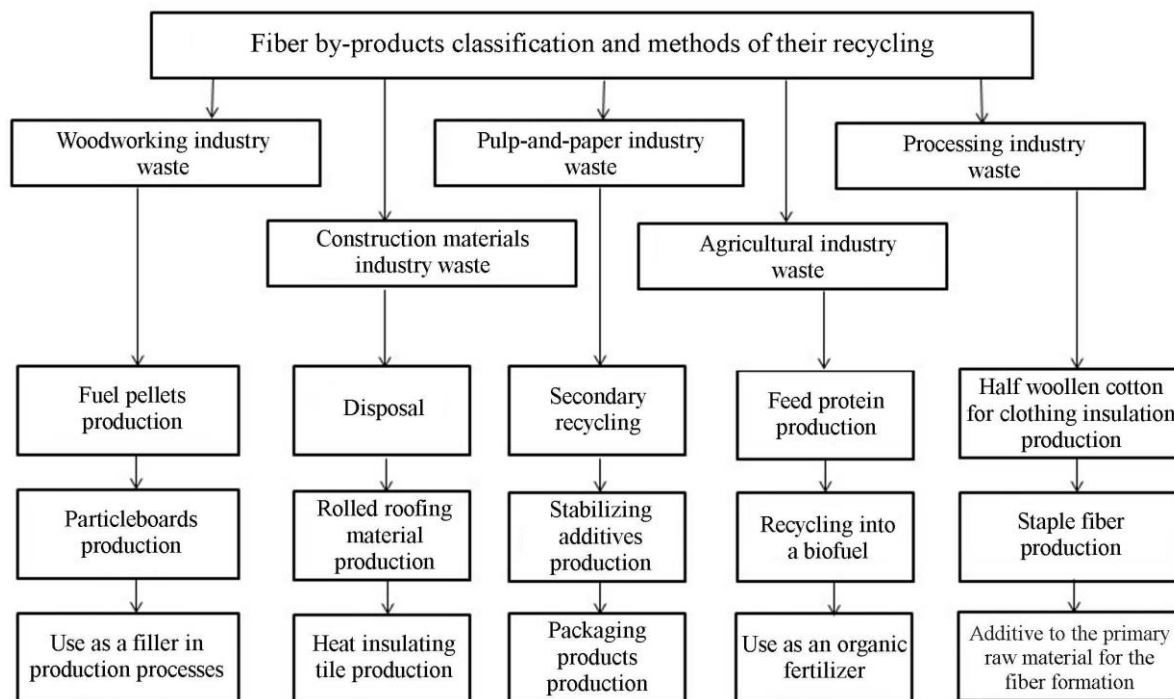


Figure 2. Fiber by-products classification and methods of their recycling.

One of the ways of the pulp-and-paper waste recycling is a granulated products manufacture. At the tech park of the Belgorod State Technological University named after V.G. Shukhov, the resource-saving complex was developed, which is dedicated to the production of the granulated stabilizing additive for stone-mastic asphalt-concrete mix based on pulp-and-paper waste (Patent #2542010 RF, C04B 26/26, C08L 95/00). In this paper analysis of the complex operation has been conducted and the technological complex was discussed, in order to develop methods of its operational effectiveness improvement.

3. Technological complex operation analysis

The technological complex for pulp-and-paper waste (PPW) recycling is a set of stages performed in sequential order: initial PPW storage, batching and transporting it to the shredder, two-stage grinding, first in the shredder and then in the rotary-hammer crusher. The grinded particles, size of 1-2 mm, with the airflow enters the cyclone-discharger, where material is settling and air goes to the baghouse filter where dust is removed. Settled in the cyclone unit material goes into the unit where materials mixing takes place and then into the chamber of plane-matrix granulate extrusion. The exiting granules go through drying and classification by spillage in the spiral-drum dryer unit. After classification, the product enters a feeding box of bucket elevator and then goes to the storage bunker.

The analysis of material flows in the fiber by-product recycling technology demonstrated that the settling degree of finely-dispersed grinded cardboard particles in the cyclone unit is less than 70% and most of the material is lost in the aspiration system. To minimize material loss, it is worthwhile to add a device for preliminary microgranulation into the technological complex for the purpose of the grinded cardboard particles settling degree increase in the cyclone unit.

It was established that in dust collecting and pneumotransporting equipment the particle coagulation in the flow is very important, which can be thermo, gradient and turbulent, which is determined by the acceleration mechanism of particles with different size and density.

The conducted analysis of all components influence demonstrated that a dominant impact on the grinded pulp-and-paper particles agglomeration in the moving flow is done by the turbulent coagulation, which is determined by the density difference, kg/m^3 , disperse phase (ρ_m) and disperse medium (ρ_g), speed (v_g , m/s), viscosity (ν_g , m^2/s) of gas. The coagulation constant of acceleration mechanism K_{accel} , (m^3/s) depends on the particle size also (d_p , m), flow length (l , m) – coefficient β , which characterizes particle size distribution (taken to be equal 1), and is calculated by the formula:

$$K_{accel} = \pi \frac{\rho_m}{\rho_g} \frac{v_g^{9/4}}{l^{3/4} \nu_g^{5/4}} \beta d_p^4, \quad (1)$$

The mean particle mass m_p , kg, at the point of time τ can be determined by the formula:

$$m_p = \frac{z}{n} = \frac{z(1 + 0.5K_{accel}n'\tau)}{n'} \approx \frac{K_{accel}z\tau}{2}, \quad (2)$$

where z - particle mass concentration, kg/m^3 ; n' - initial particle concentration, $1/\text{m}^3$; τ - coagulation time, s.

Diameter of the increased particle as the result of the coagulation process is determined by the formula and compared with the initial diameter:

$$d_p = \sqrt[3]{6m_p / \pi \rho_p}. \quad (3)$$

Based on the formulas (1-3) calculation of the 0.5-2.0 mm size particle coagulation in the cyclone-discharger was conducted, which is installed in the technological complex. As can be seen in Figure 2, particle coagulation depends on time and its initial size. The particle growth coefficient was calculated as a relation of the agglomerate diameter, obtained as the result of their adhesion, to the initial diameter of particles. As can be seen in Figure 3, for the fiber particles with the size of 0.5-2.0 mm the increase of coagulation time, flow speed and particle size create more favorable conditions for agglomeration, which can be achieved in the equipment with toroid-shape chambers.

The most favorable equipment for this process is a vortex plant [13-16]. For this purpose, we developed the device for pneumomechanical granulation of by-products (Patent of invention #2538579 RF). Particularly the fiber structure and enhanced particle volume concentration of grinded materials allow conducting the process of its agglomeration in material-and-air flow [17, 18].

The fiber size in grinded PPW (mostly cardboard) is 0.5-2.0 mm, actual material density $800 \pm 50 \text{ kg/m}^3$.

To determine the solid material concentration in the airflow and speed of two-phase flow the measurements of the airflow speed (v , m/s) in the technological complex at different productivity (G_s , kg/hr.) were conducted.

Table 1 presents the measurement results of two-phase flow speed in the pipe of pneumotransport system (v_1 , m/s) and in the cyclone-discharger (v_2 , m/s), and also mass concentration ($\mu = G_s/G_a$, kg/kg_a).

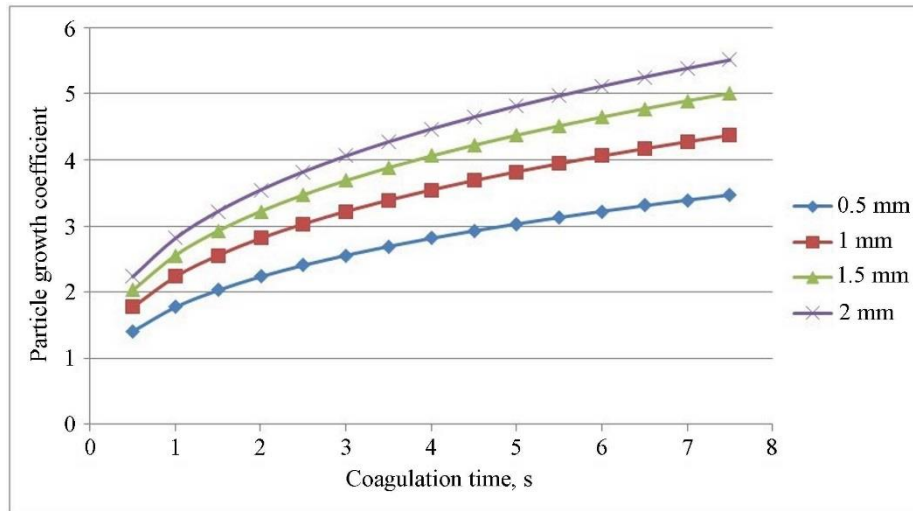


Figure 3. The dependence of particle growth coefficient on coagulation time.

Table 1. Measurement results of two-phase flow parameters of the technological complex

№	F, m^2	$v, \text{m/s}$	$L_a, \text{m}^3/\text{s}$	$G_a, \text{kg/hr.}$	$G_s, \text{kg/hr.}$	$\mu, \text{kg/kg}$	$G_{2p}, \text{kg/hr.}$	$\rho_{2p}, \text{kg/m}^3$	$v_1, \text{m/s}$	$v_2, \text{m/s}$
1	0.044	5.6	0.246	1132	0	0	1132	1.28	20.20	2.54
2	0.0407	4.0	0.163	748	160	0.21	908	1.54	13.38	1.68
3	0.033	3.7	0.122	561	180	0.32	741	1.68	10.02	1.26
4	0.0296	3.5	0.104	476	200	0.42	676	1.81	8.49	1.07

Table 1 indicates that the mass flow rate (G_{2p} , kg/hr.) and two-phase flow speed decrease when productivity (G_s) increases, and also mass concentration (μ) from 0.2 to 0.5 kg/kg_a. This range is the most promising for further by-product properties study (suspension velocity, particle drag coefficient). For the physical modeling and study of the pulp-and-paper waste granulation process, we developed the semi-industrial experimental plant (Figure 4).

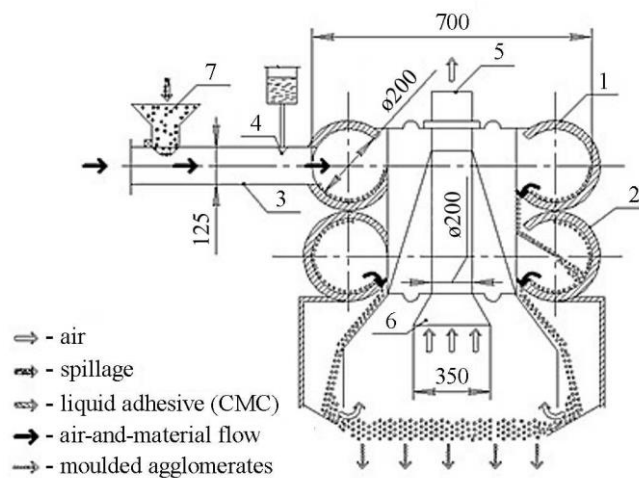


Figure 4. Plant for by-product agglomeration in the airflow.

The plant consists of two toroid-shape chambers, upper (1) and lower (2), which are situated horizontally, one above the other. The air-material mix feeds through the pipe (3) with installed nozzle (4) for liquid adhesive spray. The pipe tangentially connected with the upper toroid-shape chamber. In the toroid-shape chamber, the flow is subject to the centrifugal forces, by means of which material particle agglomeration takes place. After this, agglomerates move to the second chamber, where they are additionally being compacted and increase in size. Then particles get into the bunker, where moulded microgranulates spill down, and freed from it air moves upward, out of the bunker through the pipe (5) and the probe (6). The substandard material (spillage) enters through the auger dosing unit (7).

The agglomeration processes analysis was done in the device for pneumomechanic granulation (Figure 4) at a speed of 4-6 m/s in the toroid-shape chambers. Calculation of the two-phase flow trajectory in the toroid-shape chambers of the pneumomechanical plant was conducted with the help of computer modeling using SolidWorks 2017 Flow Simulation software. The results of numerical simulation and profile construction of the particle velocity vector when it moves in relation to the gas phase demonstrated that the dispersed phase slips in relation to the gas phase, and particle goes in spiral motion with a large lead. The agglomeration happens due to flow spiraling and fiber particle adhesion, that can be enhanced by the introduction of additives which ensure adsorptive-and-coagulative particle interaction.

As the binding additive for grinded PPW was chosen a solution of carboxymethylcellulose (CMC), which demonstrates high adsorption to paper and creates a viscous coagulation structured system. The subquality product additive (spillage) in the dispersed system acts as the centers of granulation and leads to the formation of agglomerates with increased density and size. The research of the agglomeration processes was conducted with the additive CMC (0.8-1.4) % and spillage (5-20) % of the initial material.

The following equation was obtained as a result of the conducted researches:

$$Y = 202.57 + 11.08X_1 + 58.61X_2, \quad R_{xy} = 0.997, \quad (4)$$

where Y - density of the obtained agglomerates (output parameter), kg/m^3 ; X_1 – addition of spillage into the initial material, %; X_2 - addition of CMC into solid, %. The research results were processed by software Statistica.

Figure 5 presents the improved complex, technological line of which has the plant for pneumomechanical agglomeration.

The conducted study revealed that for obtaining of the microgranules with a diameter of 3-5 mm and a density of $400 \pm 30 \text{ kg/m}^3$, in the pneumomechanical granulation plant the initial mix should contain $10 \pm 5\%$ of spillage (Retour), CMC additive is $1.0 \pm 0.2\%$ of the grinded cardboard. Based on the rheological study it was established that CMC should be fed in a form of 5% water solution into the upper chamber in the same direction as moving gaseous dispersed flow. The recommended speed in the toroid-shape chambers is (4-5) m/s.

Positioning of the pneumomechanical plant before the cyclone-discharger (item 9) facilitated a size increase of particles, which enters the cyclone unit. In the pneumomechanical plant under the influence of the centrifugal forces grinded cardboard particle agglomeration takes place. Subquality product ($10 \pm 5\%$ of spillage) is being used to create centers for microgranulation and component mix density increase. The process of agglomeration produces microgranules with a diameter of 3-5 mm and a density of $400 \pm 30 \text{ kg/m}^3$, which increases the effectiveness of its settling in the cyclone unit of the technological complex by 20% and decreases the amount of dust, which enters the baghouse filter [19].

To prevent dusting the technological line was equipped with an aspiration hood on the feeding funnel (Useful model patent #154559 RF) (Figure 5, item 5).

Using the developed by us method the aerodynamic calculation of the pneumomechanical plant and aspiration system of the technological complex was conducted, considering the concentration and properties of the dispersed fiber particles [20]. The calculation results pointed out the necessity of an additional fan installation, determined required parameters and model of the fan (Figure 5, item 12).

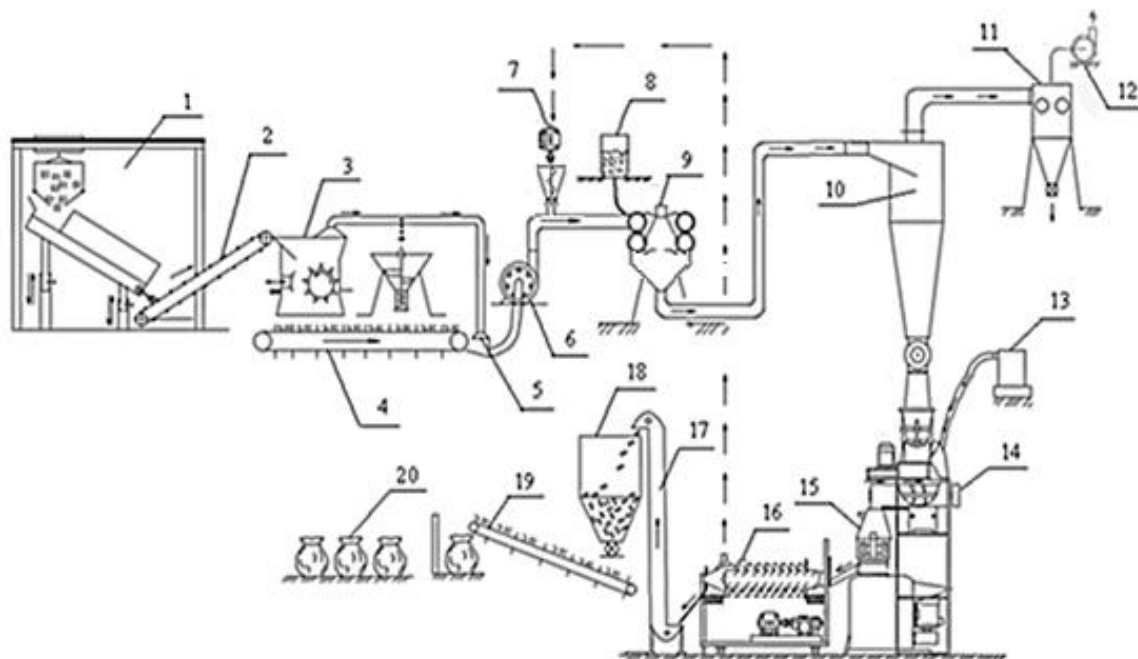


Figure 5. Improved low-tonnage technological complex for granulated products manufacture: 1 - unit for initial material feeding (cardboard, paper), 2 - belt conveyor, 3 - unit for PPW grinding (first stage in shredder), 4 - conveyor, 5 - aspiration hood, 6 - rotary crusher, 7 - auger dosing unit, 8 - tank with adhesive additive, 9 - pneumomechanical unit for microgranulation, 10 - cyclone unit, 11 - baghouse filter, 12 - fan, 13 - tank with additives, 14 - set of mixers, 15 - plane-matrix granulator, 16 - spiral-drum dryer unit with classification function, 17 - bucket elevator, 18 - storage bunker, 19 - drag conveyor, 20 - finished product packaging.

4. Technical and economic calculation

The conducted calculation of the improved complex includes: determination of the additional capital investment funds, which is needed for project development; granulated stabilizing additives output cost calculation; annual economic effect calculation.

The economic effect calculation was conducted in accordance with «Methodological recommendation for investment project effectiveness evaluation (second edition). Official edition. - M.: Economic, 2000 (Approved: Ministry of Economic Development of RF, Ministry of Finance of RF, State Committee of RF on construction, architectural and housing policy. No. VK 477 21.06.1999) ».

Effectiveness of the technological complex use for production of the granulated stabilizing additives (GSA) for stone-mastic asphalt-concrete mix based on pulp-and-paper waste is conditioned by the product output cost decrease as the result of material cost reduction, firstly, due to microgranulation process use in the pneumomechanical plant with introduction of the liquid organic adhesion carboxymethylcellulose (CMC), spillage after the classifier and material losses decrease, respectively.

The results of the conducted calculations, based on the discounted cash flow model, were used to determine the main measures of the suggested investment project effectiveness, which confirmed its feasibility. At the total additional non-recurrent expenses of 500 thousand rub. the economic integration effect, which serves as the final absolute result of the investment project realization, will be 581 thousand rub., the profitability index value, which is the degree of project profitability, - 2.1, i.e. more than 1. The payback period of the project is 1.2 years. The sum of additional profit from product sales at the wholesale price of 35000 rub. for 1 ton of (GSA) will be 481.3 thousand rub, or calculated for 1 ton – 1471.8 rub.

5. Conclusion

The conducted research of the pneumomechanical plant for grinded pulp-and-paper waste microgranulation, which is part of the aspiration system of technological complex, has confirmed the dust-collecting cyclone unit's effectiveness increase by 20%. The approximate economic effect from material losses decreases during aspiration, reloading and also the subquality products recycling will be 1471.8 rub/tons. The complex productivity with the output production of 327 tons per year will bring the economic effect of 581 thousand rubles per year.

Acknowledgments

The article was prepared within development program of the Flagship Regional University on the basis of Belgorod State Technological University named after V.G. Shukhov.

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