Ways to reduce dust burden in treating units of fibrous by-products

T N Ilyina*, M V Sevostyanov, D A Emelyanov, A B Goltsov
Belgorod State Technological University named after V.G. Shukhov, 46 Kostyukova street, Belgorod, 308012, Russian Federation

E-mail: ilina50@rambler.ru

Abstract. The characteristic of fibrous by-products and their disposal methods is given. The scheme of the technology of pulp and paper waste processing with the production of granulated products for crushed stone-mastic asphalt concrete is presented. The analysis of the material flows of the technological complex is given. The expediency of the preliminary stage of particles micro-granulation in a pneumo-mechanical apparatus to reduce dust burden and increase the efficiency of the complex operation as a whole is shown. Two-phase flow parameters of the technological complex are determined. The aerodynamic calculation of the aspiration system of the complex before and after modernization was carried out.

Introduction

The bulk of fibrous by-products (FBP) is presented by pulp and paper waste (PPW). Cellulose is the most common polymer on earth, which plays an important role in the natural carbon cycle. However, the annual waste increase of the pulp and paper industry and their environmental pollution poses a number of tasks for the PPW disposal. Cellulose is an organic compound consisting of insoluble fibers that are not broken down by the usual enzymes of the mammals’ gastrointestinal tract. The cellulose splitting in industrial conditions requires enormous energy costs [1]. Therefore, the process of FBP recycling by the volume reduction to obtain bodies of a given geometric shape and their subsequent use in various industries is currently one of the priority areas [2-6].

From the point of view of the rational nature management principle, the recovery of non-utilizable industrial waste with the creation of small low-tonnage technological complexes requires the development of special technological schemes. One of the promising ways of fibrous by-products utilization is the stabilizing additives production for black mastic asphalt concrete. Analysis of the technological line for the production of extruded by-products developed in BSTU named after V.G. Shukhov [7], showed the need to improve the complex, taking into account the physical-chemical properties of fibrous materials.

Goal, tasks, methods of study

Fibrous materials consist mainly of elongated particles - fibers, the gaps between which are filled with air in non-impregnated materials and synthetic resins in impregnated ones. The advantages of many fibrous materials are low cost, rather high mechanical strength, flexibility and convenience of processing. Disadvantages: low electrical strength and thermal conductivity, higher than that of bulk
materials of the same composition, hygroscopicity. Impregnation improves the properties of fibrous materials.

The structure of the fibrous mass of the PPW is represented by plant fibers, on the outer surface of which there is a thin shell, inside of which there is a cavity (lumen) filled with protoplasm consisting of protein substances (proteins and proteids). Up to 50 thin layers, called lamellae, are formed in the cell wall, and the inside of the cells is filled with the substance of the cell wall. In the secondary wall of the cell layered spiral structures of individual fibers alternate - fibrils, consisting of the finest submicroscopic microfibrils with a diameter of 250 nm (0.025 μm). The fibrils diameter is 0.1-0.4 μm, and the width of their bundles is 1-5 μm. In most cases, the fibrils are laid evenly in layers, and in sometimes spirally. When studying the structure of the cell wall, it is established [8] that in microfibrils there are formations that have a crystalline structure - micelles. Numerous radiographic and electron diffraction studies have shown that micellar compositions consist of individual macromolecules groups of the filamentous form [8]. The maximum lignin content (85%) reaches in the middle layers of cellulose fibers, and on the surface - 15%. When dispersing cellulose (pilling) and its derivatives, an enormous specific surface area is achieved, which ensures a high adhesiveness of interaction with the surrounding components.

Cellulose is a raw material for the paper materials production, the main characteristic of which is the weight of one square meter in grams. According to this indicator, paper is distinguished from 5 to 150 g/m², thin cardboard from 151 to 400 g/m² and cardboard from 401 to 1200 g/m². According to the fiber mixture content, paper is subdivided into the following types: thinnest of waste paper or special cellulose, thin of cellulose, half-thin of cellulose and a certain amount of wood pulp, usual of cellulose and a certain amount of wood pulp and waste paper.

Fibrous waste is formed during molding and textile processing (twisting, rewinding, dressing, laying, etc.) and in the process of refueling the spinning machine. They are subdivided into two types - fumes produced during the threading of the spinning nozzles (fiber-forming devices) and the winding yarn on the galettes and galette rag that occur during the threading period from the spinning machine galette to the threading in the spin pack (i.e. thread receivers).

At a number of enterprises methods for the use of non-returnable waste are developed. In particular, to obtain staple fibers, i.e. specially prepared fiber from the short hair - staples as opposed to continuous filament fiber, as well as for producing non-woven materials, knitted fabrics, etc. The waste of plant growing and animal husbandry, which can be used for fattening domestic animals and producing biofuels, fodder yeast, environmentally friendly insulation boards also pollute the environment [2]. The most rational solution for recycling pulp and paper wastes is their use in the production of granular stabilizing additives for crushed stone-mastic asphalt concrete (GSA CMA). The main purpose of the stabilizing additives use is to increase the thickness of bitumen films, ensuring the presence of free (bulk) bitumen and uniformity of CMA, which can significantly increase the durability of the road surface, to achieve high strength and resistance to mechanical stress and plastic deformations. In BSTU named after V.G. Shukhov a low-tonnage technological complex is designed and manufactured for the extruded by-products manufacture for various purposes (fuel pellets, organic mineral fertilizers, thermal insulating fillers, etc.), but the main role is given to the creation of GSA CMA based on shredded waste cardboard and paper [7].

Experimental part
The scheme of the technological complex for PPW recycling and their granulation with mineral additives and binders includes the following operations: storage of the original PPW; dosing and their transportation to the shredder; two-stage PPW grinding with the additives introduction into the crushed material after the shredder; sedimentation of crushed PPW in the aspiration system; composite mixture granulation in a flat-matrix granulator, followed by drying and classification of the finished product in a drum-screw drying unit; transportation of GSA for their subsequent packaging, GSA weighing and storage.
The analysis of material flows showed that more than 20% of the material is lost in the cyclone discharger and in the classifier. To improve the efficiency of the complex operation and reduce material loss, it is necessary to analyze the aspiration systems and supplement the complex with a device for preliminary pneumatic mechanical granulation of by-products, which will increase the material trapping degree in the cyclone unit and also dispose of substandard material from the classifier.

To determine the concentration of solids in the air flow and determine the speed of the two-phase flow, measurements of the air velocity ($\nu$, m/s) in the technological complex at various capacities ($G_T$, kg/h) were made.

The measurements were made using a Testo 416 anemometer. The impeller of the device was placed in the slot in front of the impact crusher where the material ground in the shredder was loaded. Then the technological complex was turned on without loading the material, and the velocity was measured with time averaging. Similarly, the velocities were measured at different capacities of the complex (160 kg/h, 180 kg/h and 200 kg/h). The results of measurements and calculations are presented in the table, where ($\nu_1$, m/s) two-phase flow rates in the pipeline of the pneumatic transport system and ($\nu_2$, m/s) in the cylindrical part of the cyclone unit.

**Table 1.** The two-phase flow parameters of the technological complex

| № S No. | $F_r$ [m$^2$]  | $\nu_1$ [m/s] | $L_{in}$ [m$^3$/s] | $G_{in}$ [kg/h] | $G_{s}$ [kg/h] | $G_{r}$ [kg/kg] | $\mu_r$ | $G_{2F}$ [kg/h] | $\rho_{2F}$ [kg/m$^3$] | $L_{2F}$ [m$^3$/s] | $\nu_1$ [m/s] | $\nu_2$ [m/s] |
|-------|----------------|----------------|---------------------|----------------|----------------|----------------|---------|----------------|------------------|------------------|----------------|----------------|
| 1     | 0.0440         | 5.6            | 0.246               | 0.314          | 1132           | 0              | 0       | 1132           | 1.28             | 0.246            | 20.20          | 2.54           |
| 2     | 0.0407         | 4.0            | 0.163               | 0.208          | 748            | 160            | 0.21    | 908            | 1.54             | 0.163            | 13.38          | 1.68           |
| 3     | 0.0330         | 3.7            | 0.122               | 0.156          | 561            | 180            | 0.32    | 741            | 1.68             | 0.122            | 10.02          | 1.26           |
| 4     | 0.0296         | 3.5            | 0.104               | 0.132          | 476            | 200            | 0.42    | 676            | 1.81             | 0.104            | 8.49           | 1.07           |

Based on the data obtained, the concentration of the solid phase in the air flow and the volume flow rate of the two-phase flow were calculated. It has been established that with a complex performance of 160–200 t/h, the speed of the gas-dispersed flow in the pneumatic transport system to the cyclone decreases from 13.5 to 8.5 m/s. The mass concentration ($\mu_r$=G_r/G_s, kg/r / kg_m) of the solid in the mixture increased from 0.2 to 0.5 kg_r / kg_m. The speed of the two-phase flow in the cylindrical part of the cyclone installation is 1.1–1.7 m/s.

The starting material for the granules production is cardboard crushed in a shredder and hammer crusher and thick paper such as Whatman paper. The true density of the crushed cardboard is 680 kg/m$^3$, the density of the crushed Whatman is 889 kg/m$^3$, the bulk density is 30-40 kg/m$^3$. The average particles size is 6.8 microns, the specific surface area is 530 ... 580 m$^2$ kg. The soaring speed of shredded paper, paperboard particles is from 1.1 to 4.4 m/s for particles of equivalent diameter of 0.50 ... 0.8 mm. The crushed particles have a fibrous structure that complicates their deposition in the cyclone-discharger. The deposition efficiency was 72-75%. With crusher productivity G_r = 160–200 kg/h, the loss of material in the form of reduced dust was 45–50 kg/h.

To increase the efficiency of the deposition of “light” particles of fibrous material, it is necessary to increase the dispersed phase density entering the in the cyclone unit, as well as the speed of their soaring, i.e. to agglomerate particles in the air flow.

Our theoretical studies of the interaction of particles in the air flow have shown that agglomeration of fibrous particles in the centrifugal field of toroid-shaped chambers is most effective [8]. For this purpose, a pneumatic-mechanical apparatus was developed [9], its experimental studies were carried out, the
aerodynamic mode of its operation was chosen. It was established that the flow rate at the entrance to the apparatus should be 6-8 m/s, in toroidal chambers 4-6 m/s.

To obtain microgranules of a given size and density, the mixture composition was developed, including shredded cardboard, the sub-quality products and a binder. The addition of 10±5% of the sub-quality products play the role of granulometry centers in the sintering process. Sodium salt solution of carboxymethylcellulose in the amount of 1.2±0.2% of the starting material was used as a bonding additive. In the agglomeration process, granules of increased density (ρ=400±30 kg/m³) and dimensions (d=2.0-3.5 mm) were obtained in the pneumatic-mechanical device.

The device installation for pneumatic-mechanical granulation in front of the cyclone unloader in a complex process line and the size increase of the agglomerates entering the cyclone unit resulted in an increase in the degree of their capture in the cyclone unloader of the technological complex up to 90-92%, that reduced material loss in the form of dust to 16-18 kg/h. The calculation of pressure losses of two-phase flows was made according to our developed method [10, 11] depending on the content of fibrous materials taking into account their specific surface and density. The coefficient of hydraulic friction of a two-phase flow was determined, which was 0.32, the coefficient of local resistance of the pneumatic-mechanical device (ξ_pmu= 88). The pressure loss of the pneumatic-mechanical apparatus (ΔP_pmu = 3900 Pa) is higher than the pressure loss of the cyclone unit (Δcu = 1540 Pa), which is connected with a higher speed of air-material flow in toroid-shaped chambers (υ=6 m/s) compared to the cyclone chamber.

After upgrading the technological complex connected with the pneumatic-mechanical device introduction, the pressure loss of the aspiration system increased by 28%. To compensate the pressure loss, the selection of the air ventilation unit VC 5-35 №4 was made, which should be installed after the bag filter.

Summary

The analysis of the aerodynamic operating mode of the technological complex installations for the processing of by-products has shown the expediency of preliminary crushed particles of the fibrous structure micro-granulation in a pneumatic-mechanical apparatus. This allowed increase the efficiency of the complex operation by reducing material losses during aspiration, as well as by disposing subquality products in the sintering process. Modernized technological complex is proposed, the results of aerodynamic calculation of the aspiration system before and after modernization are presented.

References
[1] Nikitin N I 1962 Wood and cellophane chemistry.
[2] Sivachenko L A, Sevostyanov V S, Ilyina T N 2017 Problematic tasks in the field of resource-saving technologies (Materials Science Forum) 548-553.
[3] Makarenkov D A, Gonopolskiy A M, Nazarov V I, Trefilova Ya A 2013 Choice of the granulating equipment of multicomponent polydisperse mixtures with secondary material resources on the basis of the system analysis (Bulletin of the Moscow Region State University. Series “Natural science”) 1 49-64.
[4] Glagolev S N, Sevostyanov V S, Ilyina T N, Uralskiy V I 2010 Tecgnological modules for complex reprocessing of anthropogenic materials (Chemical and petroleum engineering) 9 43-45.
[5] Sevostyanov M V, Ilyina T N, Sevostyanov W S, Emelyyanov D A 2014 Methodological Principles of Agglomeration Processes Improvement in Technologies of Disperse Materials Processing (Research Journal of Applied Sciences) 11 (9) 738-744.
[6] Glagolev S N, Sevostyanov V S, Gridchin A M, Uralskiy V I, Sevostyanov M V, Yadkina V V 2013 Resource and energy saving modules for complex utilization of technogenic materials (Bulletin of BSTU named after V.G. Shukhov) 6 102–106.
[7] Patent 2567519 Russian Federation, MPK A23K 1/20. Production line and process for extrusion of man-made fibrous materials S.N. Glagolev, V.S. Sevostyanov, A.M. Gridchin, M.V. Sevostyanov, P.A. Trubaev, V.I. Uralskiy, V.I. Filipov, A.V. Koshcukov (2015), Bul. № 31.
[8] Korda I, Libnar Z, Prokop I 1967 Paper stock break.
[9] Ilyina T N, Boychuk I P, Emelyanov D A 2016 On the interaction of particles of fibrous materials in the air flow (Bulletin of BSTU named V.G. Shukhov) 6 116-121 (In Russian)
[10] Patent 2538579 Device for pneumatic granulation of man-made materials. V.S. Sevostyanov, T.N. Ilyina, M.V. Sevostyanov, D.A. Emelyanov, A.V. Koshukov 1 (2015).
[11] Minko V A, Ilyina T N, Emelyanov D A 2016 Methodological bases for calculation of the aspiration ventilation systems (International Journal of Pharmacy Technology) 4 (8) 26644-26652.
[12] Minko V A, Ilyina T N, Minko A V, Emelyanov D A 2016 For two-phase flow duct calculation (Bulletin of Tambov State Technical University) 4 (22) 648-656.