Resource and energy-saving technologies of complex processing and utilization of technogenic materials

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Abstract. At present, a very topical environmental problem is the increase in the formation of industrial and solid municipal waste (ISMW). This leads to a deterioration of the ecological situation, and, consequently, threatens human life and health, has a detrimental effect on the biosphere as a whole. Therefore, a special place in the organization of rational use of natural resources should take a comprehensive system of measures for the processing and utilization of various man-made materials that are the product of human production. The purpose of research and development projects is the creation of resource-saving technology, technological systems and special equipment for integrated processing and recycling of various man-made materials. One of the conditions for the implementation of resource-saving technology is the use of internal energy and material resources of the processing plant.

Keywords. Complex processing, utilization, technogenic materials, resource saving, energy saving, industrial and solid municipal waste.

1. Introduction
At present, a very urgent problem is the increase in the scale of solid municipal waste (MSW) and the urgent need for their integrated processing. Partial sorting of MSW with the subsequent disposal of non-utilizable waste at landfills [1] is a highly inefficient method of disposal [2, 3], and the existing technologies for the combustion of MSW are an additional source of global pollution by emissions [4]. In addition, any improvements in combustion technologies do not eliminate the formation of dioxins and furans, which, in turn, necessitates the subsequent disposal of significant volumes of harmful substances after cleaning the flue gases. Existing technologies are economically unprofitable and are realized only under conditions of state subsidies [5].

2. Technologies of complex processing and utilization of technogenic materials
In recent years, due to the steadily increasing environmental tensions in large cities, metropolitan areas, at the highest state level, more and more attention is paid to the development of resource-efficient technologies for complex processing of MSW [6-8].
Each technological direction of complex processing of MSW exists as a set of separate processes and is economically inefficient due to high cost (due to the need to acquire external energy and material resources).

In connection with the above, the purpose of research and experimental development is the creation and mastering of the technology of complex processing of MSW.

Research and production groups of LLC TC "Ecotrans" and BSTU named after V.G. Shukhov are carried out the development of resource-saving technologies and special equipment for complex processing of various technogenic materials [9, 10]: waste wood processing industry, organic waste (polymers, plastics, etc.), basalt waste, cullet, etc.

In this technology of complex processing of MSW, the implementation of various technological directions (flows), connected with each other and ensuring the use of internal energy and material resources is carried out. At the same time, there is no need to purchase these resources from outside. Combining the areas of complex processing with technological interconnections makes it possible to obtain a new technology that ensures low cost due to the use of domestic energy and material resources. The variety of the products obtained, which can be produced at low cost using the principle of technological interconnections, is quite large and is determined by the specific conditions of production (the nomenclature of waste, the need for any product, etc.). Figure 1 presents the block diagram of technological processes for the specific conditions of LLC TC "Ecotrans".

2.1. Areas of integrated processing of MSW
Taking into account the accumulated experience and the requirements of maximum economic efficiency for LLC TC "Ecotrans", the most appropriate are the following areas of integrated processing of MSW:

I. Reprocessing MSW to obtain RDF-fuel.

II. Production of briquetted products for various purposes from wood waste, with their subsequent processing to produce thermal or electrical energy in heat and power generators.

III. Production of hydrocarbon fuels from raw materials, resulting from thermolysis. This technology of processing of technogenic materials is implemented in LLC "Research and production enterprise Thermolysis".

IV. Recycling of polymeric wastes from MSW and production of silica-polymer-containing products from them.

V. Comprehensive processing and recycling of basalt fiber multifunctional wastes for the purpose of producing dry building mixes with fibro-fillers.

The main objective of the proposed technology for complex processing of MSW is to ensure a minimum amount of waste to be transferred to a landfill for disposal. This is possible with very careful separation of the mass of waste into components and the full use of the organic part of MSW. This requirement is implemented in the preliminary preparation of raw materials for subsequent processing. In the absence of sales / consumption of the products produced in any of the directions, the prepared raw materials are sold in other resource-saving technologies.

Technological operations of preparing MSW for further processing include: sorting of waste, grinding them to the required size and drying to 8-10% moisture. The prepared raw material is further processed in accordance with the requirements imposed on the final product. The final products of complex processing of solid chemical waste are:

- According to item I:
  a) loose, non-caking mass with a particle size of not more than 25x25 mm - RDF-fuel for cement, lime and expanded-clay furnaces;
  b) loose briquettes produced by a vibroimpulsive press - fuel for cement, lime and burned furnaces, supplied with a burned material.

- According to item II:
  a) high-quality briquettes from crushed wood without inclusions of high-polymer materials
  b) fuel dust and lower quality briquettes for own consumption from polluted wood with inclusions of various materials.
Figure 1. Scheme of separate process streams with internal technological connections.

- According to item III: electric power produced by a 200 kW diesel generator and light heating oil for diesel engines of excavators, bulldozers, tractors, cars, etc.
- According to item IV: plastic pipes, piece plastic products with various fillers, etc.
- According item V:
  a) piece plastic products with a filler - micro powder from basalt waste, ready-mixed concrete and products from it with the addition of crushed basalt fibers - fiber fillers;
  b) a heavy ground for pouring out the MSW on the landfill, obtained by styling of disposal basalt fiber with soil impurities.

Each of the technological operations of this technology has a technical, economic and environmental focus and can be used in real production. However, the implementation of the above technologies requires specialized equipment that takes into account the various physical and mechanical characteristics of man-made materials: various densities, geometrical sizes and forms, low flow ability, high humidity, etc.
2.2. Processing of technogenic fibrous materials

In the developed technology, innovative processes are implemented for the complex processing of MSW, such as high-speed grinding of wet raw materials in the stream, contact drying of crushed raw materials, thermolysis, etc. One of the promising areas in the field of resource conservation is the processing of anisotropic and complex in composition man-made fibrous materials, in particular basalt fiber waste [11]. By origin, they can be divided into the following groups: 1 - waste is generated during the production of insulating materials; 2 - waste from the construction industry; 3 - greenhouse waste, which are basalt fiber mats with rhizomes of plants, etc.

As a result of processing, basalt fiber can serve as a fiber filler of various composite mixtures and products. The peculiarity of basalt fiber processing is that the waste is initially a single conglomerate containing various inclusions (figure 2) [12, 13].

**Figure 2.** Waste of basalt fiber.

As a result of the conducted research to study the specifics of processing and utilization of basalt fibers, a technological complex was developed for the processing of technogenic fibrous materials (figure 3).

**Figure 3.** Technological complex for processing of technogenic fibrous materials: 1 - hoist; 2 - loading container; 3 - receiving tray; 4, 12, 17 - plate conveyor; 5 - additive dispenser; 6 - volumetric dosing; 7 - hammer crusher; 8 - cyclone; 9 - sleeve filter; 10 - cell feeder; 11 - vibration centrifugal unit; 13 – drum-screw unit-classifier; 14 - elevator; 15 – fan; 16 - bunker; 18 - scales; 19 – big bag.
The advantages of the technological complex developed by us are its versatility - the possibility of obtaining a wide range of products from various technogenic fibrous materials.

The vibration-centrifugal unit developed by us (figure 3, pos. 11) [14-16] provides complex processing of man-made fibrous materials and the production of various types of products for use in innovative technologies: DE agglomerated basalt waste (fiber length \( l = (5 \div 15) \cdot 10^{-3} \, \text{м} \)) dry construction mixtures, thermal insulation coatings, concrete products, etc; fine fiber filler \( l \leq (5 \div 10) \cdot 10^{-6}\,\text{м} \)-fillers of nanostructured composite mixtures (figure 4), mechanically activated of silica-containing composite mixtures with air and hydraulic binders; highly concentrated microfiber fillers in granular form, etc.

![Figure 4](image-url)

**Figure 4.** Microfiber fillers from finely dispersed basalt fibers with varying degrees of magnification; grinding time: a) 5 min; b) 10 min; c) 20 min.
The resulting types of products can be used both in traditional building technologies and in promising innovative technologies, for example, in the production of architectural and building products using 3D printing.

One of the areas of use of basalt fiber as a fiber filler is the production of polymeric products for various purposes. Raw materials for the production of these products can be recycled technogenic polymeric materials. For the production by extrusion of compacted polymer products based on technogenic polymeric materials, a technological complex was developed (figure 5).

Technological complex works as follows: the source material using hoist 1 is fed to the receiving tray 2, in the lower part of which a belt conveyor 3 is installed. Then, using a plate conveyor, the raw material enters the rotor-centrifugal unit of combined action 4. In the coarse grinding chamber the material is crushed by disk mills and under the action of the air flow, moves to the fine grinding chamber, where it is ground by needle-milling working parts to a powder state. After the rotary centrifugal unit of the combined action, the raw material enters the separator 5 and is divided into fractions, large of which are returned to the grinding sludge. The material crushed to the required size enters the cyclone 6. When precipitated, it is dosed into the screw mixer 7, where it is mixed with additives supplied from the bunker 8. The composite mixture enters the receiving funnel 9 of the elevator 10, which raises the mixture into the receiving bunker 11. Using a cell feeder 12 in a certain dosage, the material enters the auger thermal heater 13, where, under the influence of high temperature, it turns into a homogeneous mass. Then it enters the extruder with an annular matrix 14. The extruded mixture through the plate conveyor 15 enters the drum-screw unit 16, where the material is cooled. The cooled granules are weighed on scales 17, packed in big bags 18 and shipped to the warehouse with the help of a hoist 19.

Figure 5. Technological complex for the production of extruded products from man-made polymeric materials: 1, 19 – hoist; 2 — receiving tray; 3, 15 – lamellar conveyor; 4 – rotary centrifugal unit of combined action; 5 – separator; 6 – cyclone; 7 – screw mixer; 8 – bunker of additional components; 9- receiving hopper; 10 – elevator; 11 – receiving hopper; 12 – cell feeder; 13 – screw thermal heater; 14 – extruder with ring die; 16 – drum-screw unit; 17 – scales; 18 – big bag.
In the processing of technogenic materials, one of the energy-intensive stages is the grinding process [17, 18]. In this regard, our research is aimed at the development and technological improvement of multifunctional grinding equipment. In the development of energy-efficient equipment, we paid special attention to the physical and mechanical characteristics of man-made polymeric materials such as: elasticity, plasticity, melting temperature, etc.

The combined-action rotor-centrifugal unit developed by us (figure 6) takes into account various technological conditions for processing technogenic polymeric materials, their physical and mechanical characteristics: the initial state of materials (shape, size, flow ability, etc.) and their strength characteristics [19-21]. The design of the unit allows realizing the possibility of varying the tearing and abrasive force, the degree of thermal heating of the material and its cooling. In the rotor-centrifugal unit of combined action, high durability of the most wear-out assemblies and parts of the unit is provided, the possibility of introducing additional components into the unit to obtain composite mixtures, the stepwise grinding process of man-made polymeric materials, the increased energy intensity of the second stage and the use of working bodies with a developed working surface - a needle cutter [22-24] and others. The rotor-centrifugal unit contains a body consisting of two crushing chambers 1 horizontally placed one behind the other and fine grinding 2 [25, 26].

![Figure 6. The rotor-centrifugal unit of combined action: 1 - crushing chamber; 2 - fine grinding chamber; 3 - crushing chamber shaft; 4 - crushing chamber rotor; 5 - needle milling tools.](image)

Inside the crushing chamber 1, there is an eccentric set about the axis of the cylindrical body of the bandage, which is lined with removable elements (profiled plates). On the shaft 3 is the rotor of the crushing chamber 4 with cutting elements in the form of disc mills. In the second chamber (fine grinding chamber) 2, needle-milling working bodies are installed 5, which are made of a set of core elements assembled in bags and rigidly fixed on the holder. In the rotary centrifugal unit of the combined action, the principle of stepwise grinding with the realization of the combined effect on the processed material is implemented. This ensures the reduction of energy-intensive grinding process, as well as expands the technological capabilities of the unit.

3. Results
As a result of research conducted by the creative group of employees of BSTU named after V.G. Shukhov and LLC TC “Ecotrans”:

1) an innovative resource-energy-saving technology and special equipment for complex processing of municipal solid waste have been developed;
2) promising areas of the developed technology have been identified;
3) the specificity of processing basalt wastes and technogenic polymeric materials was studied;
4) technological complexes for processing technogenic fibrous materials and producing a wide range of extruded products from technogenic polymeric materials have been developed;
5) special equipment has been developed that takes into account the specifics of processing anisotropic and technogenic materials that are complex in composition.
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