Perspectives of bark dump recycling at wood processing enterprises

F Svoykin*, A Birman, I Bacherikov, O Mater, V Bozhbov

1St. Petersburg State Forest Technical University, 5 Institutskiy Lane, St. Petersburg 194021, Russian Federation

*Corresponding email: svoykin_fv@mail.ru

Abstracts. Woodworking and pulp-and-paper mill areas accumulate significant volumes of wood debarking waste, which is stored in bark dumps with a volume of up to 1 000 000 m³. Methods for recycling bark, both fresh and stagnant, are proposed through the production of fuel briquettes and pellets, composting, building materials, and the use of combustible gases that accumulate in the depths of the old bark layers. Characteristics of extractive substances obtained from bark are given and their fields of application are considered. Possible ways of recultivation of old bark dumps, ways of waste water treatment are offered. The recommendations on reduction of technogenic hazard of bark dumps are given and the necessity of constant monitoring of such objects is grounded. The technological scheme of complex use of bark dump materials on the basis of developments of Saint-Petersburg State Forest Technical University is proposed.

1. Introduction

Almost all timber materials are subject to debarking at woodworking and pulp and paper mills (PPM) [1, 2]. Manufacturers need to choose rational methods of bark recycling, which accounts for 10-15% of the volume of stem wood. Recycling is necessary because bark contains substances extracted by water, which have a harmful effect on the flora and fauna of water and soils.

Wastewater flows containing bark are a consequence of almost all operations related to the processes of processing and storage of bark. Thus, the bark-containing effluents of the pulp and paper mill make up 10-12% of the total amount of wastewater. Table 1 shows the characteristics of only the press equipment of the pulp and paper mill from the position of formation of the bark-containing sewage. Practically the presses are not able to dehydrate the bark to a relative humidity of 55-60% [3].

| Type and model of press        | Humidity after the press, % | Wastewater volume, m³/h | Bark concentration in wastewater, mg/l |
|-------------------------------|-----------------------------|-------------------------|----------------------------------------|
| Roller press from «Fulton»    | 64                          | 1.1                     | 1 200                                  |
| Screw press with screw diameter; mm; 400; 550; 750 | 62                          | 0.1; 0.2; 0.3           | 1 500                                  |
| Chain press: DO-318; FMP-39; FMP-51 | 64                          | 1.0; 1.4; 1.8           | 2 100; 2 000; 1 900                    |
| Drum press from «Enso»        | 55                          | 1.5                     | —                                      |
| Piston press from «Kovan»     | 55                          | 1.75                    | 2 100                                  |

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It should be noted that various physico-chemical agents are widely used to clean bark dump infiltration from suspended and dissolved particles. They allow to remove almost all suspended and biochemical non-oxidizing substances, as well as to perform their recovery. The most likely combination of cleaning methods is the use of membrane and anaerobic methods.

Membrane methods of wastewater treatment are widely used at the enterprises of chemical wood processing [4]. The main membrane separation methods include reverse osmosis, ultrafiltration, electrolysis, evaporation through the membrane, electro-osmofiltration [5].

At power inputs of about 3 kW/h per 1 m³ of water, at a temperature of 25°C, pressure drop of 3.6 MPa on 0.46 m² of membranes, at the initial content of dissolved substances of 3.5 g/l it is possible to reduce the filtrate contamination in biochemical oxygen demand and chemical oxygen demand by 93%, in dissolved substances – by 95% [6].

In most cases, millions of cubic meters of bark are taken to waste dumps with the area of tens of hectares. These areas are completely removed from economic use. Rotting bark becomes a breeding ground for plant and insect disease carriers. Runoffs from rainfall and snowmelt worsen the ecological situation in the surrounding areas and water areas. Due to self-oxidation, fires occur, causing fires and polluting the air basin [7]. Modern world practice of bark utilization is primarily designed to work with fresh bark. Here a number of technically and economically justified directions of processing are opened. Below are the main directions and approaches to the recycling of bark, both fresh and rotting [8-11].

2. Methods and Materials

2.1. Burning of bark to produce heat and/or electricity

Bark is a low-grade fuel. The fractional composition of the bark formed on debarkers is a mass with pieces from 5 to 200 mm (sometimes larger) with uneven humidity. Absolutely dry bark weighs 1 solid m³, e.g. 740 kg for spruce and 530 kg for pine, which does not differ much from wood. Compared to fossil fuels (e.g. coal), bark ashes contain less silica, aluminum and iron oxide and lime [12]. On average, the composition of combustible bark and wood is the same, table 2.

| Fuel type | Composition of the combustible mass, % |
|-----------|----------------------------------------|
|           | C          | H          | O          | N          |
| Wood      | 51.0       | 6.1        | 42.3       | 0.6        |
| Bark      | 51-52      | 5.9-6.3    | 40.8-42.5  | 0.6-0.9    |

The humidity of bark produced by debarking is usually higher than critical. Before such bark enters the furnace it is necessary to reduce it to 50-60%. This is achieved by means of bark squeezing presses or by drying the bark with boiler exhaust gases, ventilation emissions and other secondary thermal energy resources.

The higher heat of bark combustion is not much different from the higher heat of wood combustion, and sometimes exceeds it, because the bark contains more lignin and resins than wood. Thus, the highest heat of dry mass combustion of pine wood is 4 186.8 J/kg, pine bark – 4 850.8 J/kg [13]. Analysis of numerous experimental data on the dependence of the lower working heat of combustion $Q_H$ on humidity shows that it can be expressed by the formula:

$$Q_H = (4660 - 55 \times W) \times 4186.8 \ J / kg,$$

where, W is the humidity of the bark, %.

The theoretical burning temperature of the bark at a humidity of 50% varies between 1 473–1 673 K. Thus, the composition of the combustible mass, the higher heat of combustion, the volatile matter yield and the combustion temperature of dry bark do not differ much from that of wood [14]. Poor bark permeability is caused by its jamming or compaction in bunkers and transport systems [15].
There are ways to reduce the humidity of the bark without the formation of waste water. One of them is bark drying, which is appropriate if the initial bark humidity does not exceed 75%. Modern technology offers a range of machines and mechanisms with different degrees of efficiency allowing to clean the bark from foreign inclusions, grinding and dehydration of the bark [15-17].

The leader in the production of bark-oriented boilers is the Finnish company «Värtsila» (boilers of «Bio Power» series). The cost of a complete installation, depending on the capacity and type of energy produced (hot water, steam, electricity) varies between 10 000 000 – 15 000 000 euros. It is known from the scientific sources that capital investments in bark combustion plants are 3-4 times higher than for fossil fuel plants. However, calculations show that these costs pay off in less than 1.5 years compared to light fuel and in 3.5 years compared to heavy fuel [8].

2.2. Obtaining extractive substances from the bark
The bark of a number of tree species (oak, willow, spruce, fir, larch) contain tannides – substances used for tanning leathers. The coniferous bark is subsequently extracted to produce tanning extract and pectin. Resinous substances derived from the bark of coniferous trees are a complex of higher fatty acids, aliphatic alcohols, sterols and esters. From these compounds the form of the food additive for animals is received.

The solid residue of the bark after extraction is a porous carbon material with high absorbability. This property is used for the application of nitrogen and phosphorus-containing additives necessary for the production of quality fertilizers. In the course of complex processing of coniferous bark it is possible to receive fir oil, coniferous balm, tannins, dyes and carbon sorbents (active coal). Aspen bark is used to produce vitamin and fodder additives and fertilizers. Birch bark is used to produce betulin and suberine substances to treat wounds and burns, antioxidants and sorbents. There is a lot of experience in processing birch bark with tar with a yield of 25% of the mass of dry birch bark. The forehead, the content of which in the birch bark is 60-80% of its mass, can be processed into flour suitable as a filler of synthetic adhesives. Tannins, after extraction of tannides, are partially or fully used as fuel or raw material for the production of cardboard, furfural, ethanol, fodder yeast, wood-based panels and other materials [1, 2].

2.3. Bark fertilizer
Work on the use of bark of different species and the degree of reclining on agricultural fertilizers has been actively carried out in various countries over the past sixty years. Bark waste is a natural organic fertilizer and has great humus potential. Phloem and near-cambial parts of the bark are rich in nutrients that are essential for the development of microorganisms. Possessing natural porosity and high moisture capacity, the bark accumulates and retains moisture well, promotes soil aeration and stimulates soil bacteria activity. The bark contains organically bound nitrogen in the amount of up to 3.83%, which becomes available for plant nutrition with its slow, lasting 5-7 years, decomposition in the soil. Along with nitrogen, the bark contains the following chemical elements: calcium up to 2 500, magnesium up to 600, potassium up to 300, phosphorus up to 200, manganese up to 40, boron up to 3 mg per 100 g of dry matter. Fresh bark of bark dumps is stored in pits up to 5–10 m high on hard-coated sites and periodically turned over for more effective aeration. In some cases compost is mixed with manure, bird droppings and mineral fertilizers containing nitrogen and phosphorus [2]. The complexity of this direction of processing is mainly in the economic plane, in the absence of guaranteed sales of bark fertilizer at prices acceptable to the producer and potential consumer.

2.4. Bark utilization for fuel briquettes and raw materials for pyrolysis
Debarking waste is used to produce fuel briquettes. The density of briquettes is 1 000-1 100 kg/m³, the bending strength is 1.5 MPa, and the combustion heat is 16-17 J/kg. [18, 19] The bark is ground in a hammer crusher or rotor crusher, then dried in drum or pneumatic dryers [20, 21]. Dry matter (up to 15% moisture content) is pressed in matrix, screw or roller presses. The quality of fuel cells (briquettes or pellets) obtained from bark is relatively low due to high ash content and sulphur content. They belong to the «black» or industrial class and, accordingly, their cost is low.
The St. Petersburg State Forest Technical University (SPbFTU) has developed a project for obtaining liquid products – fuel briquettes and raw materials for pyrolysis. The essence of the development is shown in the diagram, figure 1. This technology is implemented using both Russian and imported machinery and equipment. At the same time, it is economically reasonable to have own pyrolysis production, and, most importantly, to obtain the finished product – charcoal – at the end of the process [22].

2.5. Building and structural materials made of bark
Experimental studies conducted in Russia and abroad have allowed to develop a number of construction and structural materials on the basis of bark and various binders: «Korolit», «Korobeton», bark slabs and bark-plastic materials.

Korolit is an analogue of arbolit, in which bark crushed into fractions of 2 to 10 mm in size in combination with cement is used as a filler. The density of the obtained boards is 750...800 kg/m³, the compressive strength limit is 2.5...3.5 MPa. This material is fire and frost resistant. The use of korolit along with arbolite and instead will reduce construction costs, save wood used as a filler in the arbolite.

The most interesting are bark slabs without binder, whose function is performed by natural phenolic compounds, which are in the bark in greater quantities compared to wood. As a source material spruce bark is used, which is crushed to particles with sizes of 10...12 mm, dried to a humidity of 10...12%, sent for secondary crushing in a hammer mill and sieved through a sieve with cells of 3 mm. The pressing is carried out in two stages: firstly, cold pressing, then hot pressing at a pressure of 5 MPa with a holding time of 1 minute per each millimeter of the plate thickness at a temperature of 150°C. The resulting boards are used as an insulating structural material. Development of industrial technology for production of bark plates without is a rational direction of plate production from this type of raw material.

Wood-bark boards with binder can be single-layer (100% debarking waste) and three-layer with special chip outer layers and an inner layer of bark. The optimal size of bark particles for single-layer boards and the inner layer is a fraction of 2...7 mm. The density of the boards is 800 kg/m³. Urea-formaldehyde resins can be used as a binder in barkwood boards. Three-layer bark wood-based panels with outer layers of wood chipboard have high physical and mechanical properties, do not differ in appearance from chipboard, and in terms of thermal conductivity, bio- and fire resistance exceed them [23].

Bark can be used in the inner layer of three- and five-layer chipboards. Three-layer boards are 1.2-1.5 times stronger than single-layer boards when containing bark in the inner layer. The inner layer can consist of 40-50% shredded birch bark. Lower results are obtained by using aspen bark – it is necessary to increase the binder content in the inner layer from 9-9.5 to 10.5-11% (from the weight of absolutely dry wood).

2.6. Recommendations for possible processing and reduction of the technogenic hazard of old bark dumps
Old bark dumps in the forest complex of the Russian Federation are not atypical objects. Their age is more than 40 years, the volume is 500 000-1 000 000 000 m³. Such bark dumps are typical for enterprises that have no possibility to process waste and have to get rid of bark in order not to clutter production areas and carry the so-called "burdensome waste". Such enterprises should be provided with a reasonable set of long-term measures to dispose of or conserve the bark dump.

Layer-by-layer analysis of the bark dump material allows us to speak about significant differences in the physical and chemical properties of its material, which differs in density, water saturation, degree of biological activity, fractional composition and a number of other indicators. Correspondingly, today there is no single technological scheme, which would allow to dispose of all layers of the bark dump with equal efficiency on a single type of liquid products.
Using the experience gained at SPbFTU, a number of scenarios for the disposal (conservation, elimination) of the old bark dump can be proposed:

1. Complete removal of the bark dump with subsequent soil recultivation and landscape works in its place.
2. Preservation of the bark dump within the existing boundaries, ensuring environmental safety standards, with the possibility of collecting methane emissions for the purpose of its utilization.
3. Gradual processing of bark dump filler into liquid products with subsequent soil recultivation.

The above options have their advantages and disadvantages that are solely in the financial and economic plane. Any of the above scenarios are subject to constant monitoring and environmental protection measures related to effective treatment of infiltration and rainwater.

2.7. Bark dump conservation with use of methane emissions
This option is the least costly and includes:

- Design and organization of a unified drainage system around the bark dump to prevent breakthrough of sewage.
Organization of collection, transportation, purification and combustion of emission methane and its conversion into electric energy.

The power generating unit is powered by a system of perforated pipes embedded in an array of gas generating material and consists of two modules – gas purification and gas turbine. The use of the modules makes it possible to solve a number of tasks in a complex: to exclude methane accumulation in the bark mass, to improve the ecological condition of water and air basins, to obtain liquid products in the form of electric power of industrial parameters. According to the data of the researches carried out at the bark dump of Mondi Syktyvkar JSC, the content of contaminants in the bark dump at different depths makes up Table 3, it is established that the maximum one-time methane concentration in the bark dump material is 2 times higher than the maximum permissible concentration at the depth of 5 meters, and at the depth of 10 meters – 6 times.

**Table 3.** Content of pollutants in the soil air at different depths of the bark dump of Mondi Syktyvkar JSC.

| Name of the substance               | Concentration of the substance, mg/m$^3$ | Maximum allowable concentrations $^a$, mg/m$^3$ |
|-------------------------------------|------------------------------------------|-----------------------------------------------|
|                                    | 5 m                                      | 10 m                                          |
| Sulfur dioxide, SO$_2$              | <0.05                                    | <0.05                                        | 0.5 |
| Hydrogen sulfide, H$_2$S            | <0.003                                   | <0.003                                       | 0.008 |
| Phenol                              | <0.004                                   | <0.004                                       | 0.01 |
| Weighted substances                 | <0.26                                    | <0.26                                        | 0.5 |
| Carbon oxide, CO                    | 1.5                                      | 1.8                                          | 5.0 |
| Methane, CH$_4$                     | 103.0                                    | 300.0                                        | 50.0 |
| Alkane                              | 35.0                                     | 220.0                                        | –$^b$ |

$^a$ according to GN 2.1.6.3492-17
$^b$ isn’t regulated.

According to SP 11-102-97 "Engineering environmental site investigations for construction" (para. 4.63), soils with methane content >0.1% and CO$_2$ >0.5% are considered to be potentially dangerous in gas and geochemical terms; in dangerous soils, methane and CO$_2$ content >1% and CO$_2$ content is up to 10%; fire-hazardous soils contain methane in soil air > 5% and CO$_2$ – n-10%.

Let us transfer the obtained values of methane content in the soil air of the examined bark dump from mg/m$^3$ to the volume percent [24]. According to the Avogadro law, one mole of any gas at the same temperature and pressure occupies the same volume at standard temperature and pressure equal to 22.41383 l or 0.02241383 m$^3$.

One mol of methane (CH$_4$) has a mass of $12 + 4 \times 1 = 16$ g. The concentration of methane at a depth of 5 m is equal:

$$C = \left(103 \, mg \, m^{-3} \times 100 \% \right) / \left(16000 \, mg \, m^{-3} \times 0.02241383 \, m^{-3}\right) = 0.0144\%$$ (2)

The concentration of methane at a depth of 10 m is equal:

$$C = \left(300 \, mg \, m^{-3} \times 100 \% \right) / \left(16000 \, mg \, m^{-3} \times 0.02241383 \, m^{-3}\right) = 0.0420\%$$ (3)

Thus, according to SP 11-102-97 "Engineering and environmental studies for construction" (p.4.6.), the bark dump material should be considered potentially non-hazardous in gas and geochemical terms, as the methane content in its soil air is less than 0.1%. However, it is higher than 0.01%. Therefore, the bark dump material should be considered a gas-generating soil and, according to SP 11-1-2-97 "Environmental engineering research for construction" (para. 5.59), the bark dump should be identified as a gas-geochemical anomaly associated with gas-generating soils [25].

Based on the data of experimental studies, it can be concluded that it is expedient to organize the collection of methane emissions from the bark dump for further processing into thermal or electrical energy. At the same time, it is recommended to recultivate the upper layer and to plan the surfaces of the bark dump in order to ensure effective drainage, as well as systematic planting of the bark dump surface with fast-growing, zoned tree species with developed root system. In the case of landscape-
growing works on the surface of the bark dump will require the delivery of fertile soil on its upper part, installation of anti-slip meshes on inclined surfaces. As the preferred species of tree plantations can be recommended specimens, which are already found on the surface of the dump.

2.8. Complete elimination of the bark dump with the following soil recultivation
This option refers to the hypothetical possibility, as it requires high financial costs. The essence of it is to fully move the contents of the bark dump (after removal of inorganic components) to a prepared landfill. Requirements for the landfill: remoteness from water systems and residential areas, bunding along the perimeter, waterproofing of the base. The contents of the bark dump should be distributed over the landfill in a layer not exceeding 2 m, pressed. Natural soil is used as the top layer. Landscaping and landscaping measures are required in the future.

2.9. Gradual processing of bark beetle filler for liquid products with subsequent soil recultivation
If there is a task of stage-by-stage processing of the whole volume of bark and products of its decay into liquid products, it is necessary to split the task into two independent directions: full utilization of fresh debarking products (new bark dump) without their further accumulation; stage-by-stage utilization of the old bark dump for the products of various degrees of profitability with the further recultivation of the soil and recreation of the natural landscape. In any case, it is necessary to be aware of the fact that these areas of work are costly activities and are designed for a long period of implementation.

3. Results and Discussion
It should be noted that bark dumps, as technogenic objects, require constant environmental and fire safety monitoring. Concentration of long-term storage bark is a serious threat to the ecosystems of water bodies and adjacent territories. The bark dump produces infiltrate of VII degree of contamination and, due to the release of methane, is a potentially flammable object.

In conclusion, the coronary dump disposal should be comprehensive. Bark from onerous recycled materials can become an economically viable resource. For the majority of wood-based materials (lumber, plywood, slabs) the share of raw materials in the cost of production is about 50%. Bark is a free raw material, the money for which the enterprise has already paid.

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