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# Environmental Performance Assessment for Pulp and Paper Enterprises: Promising Waste Utilization Options

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**Abstract**—A comprehensive characterization study was carried out for liquid, gaseous, and solid wastes generated by two pulp and paper mills in Northwest Russia. An environmental impact assessment method based on the technical standards set for discharges (emissions) of priority pollutants was tested for individual process units and the entire enterprise.

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Chemical processing of wood raw materials and thermal power generation activities undertaken at pulp and paper mills give rise to gaseous, liquid, and solid wastes which, if released into environmental objects, may adversely affect their ecological condition. The detrimental environmental impact from the forest and chemical complex can be reduced above all via implementation of technological improvements and development of informative systems for pollution control on the basis of integrated indices.

The integrated pollution control implies regulating the adverse environmental impact levels and changing to advanced technologies with a view to minimize the impact exerted on ecosystems by enterprises. The implementation of eco-analytical control in the pulp and paper industry is a high-priority task which is treated appropriately by environmental legislation.

In the European countries having well-developed pulp and paper industries the impact they exert on the environment is controlled by means of technical regulation based on "best available techniques" (BAT). The law-making experience gained in EU countries in this sphere was integrated into drafting the Federal Law of the Russian Federation [1, 2] stipulating environmental (in particular, technical) standard-setting and application of "best available techniques."

Among the Russian Federation institutions that pioneered taking the BAT-based technical regulation approach to assessing the environmental performance of pulp and paper enterprises were the Institute of Ecological Problems of the North, Ural Division, Russian Academy of Sciences, Arkhangelsk Pulp and Paper Mill, Open Joint-Stock Company (OAO "Arkhangel'skii TsBK"), and Mondi Syktyvkar Forestry, Open Joint-Stock Company (OAO "Mondi Syktyvkarskii LPK") in cooperation with Viking Research Center and Northern (Arctic) Federal University.

Here, we evaluate the effectiveness and potentiality of the internationally accepted approach to environmental problem solving as applied to the pulp and paper industry in the Russian Federation. Specifically, we provide characteristics of the waste generated in the various stages of integrated processing of wood biomass and report on implementation of the integrated pollution control principle at large Russian pulp and paper mills, OAO "Arkhangel'skii TsBK" and OAO "Mondi Syktyvkarskii LPK", during the study period since 2001.

The environmental performance assessment procedure for OAO "Arkhangel'skii TsBK" and OAO "Mondi Syktyvkarskii LPK" encompassed the following aspects [3–8]: (1) analysis of technologies and equipment which are sources of pollutant discharges/emissions; (2) environmental management system auditing; (3) water consumption and water disposal analysis; (4) estimation of the pollutant discharge levels for biologically treated wastewater at the entire mill in terms of the priority indices, as well as of atmospheric pollutant emission levels (emissions

from the major process and power generation equipment); determination of the amounts of generated and used (per unit product) organic and inorganic solid waste, associated with the production activity of the mill; (5) determination of the pollutant emission/discharge levels in terms of the priority indices for each production unit and shop; (6) comparison of the actual data with the corresponding EU limit values; and (7) assessment of environmental sanitation activities.

The products manufactured by OAO "Mondi Syktyvkarskii LPK" include bleached sulfate pulp and bleached chemithermomechanical mass to be completely processed into paper and cardboard. The OAO "Arkhangel'skii TsBK" is engaged in manufacturing unbleached and bleached sulfate pulp and neutral sulfite semichemical pulp intended for processing into paper and cardboard.

Pulp production is a complex cycle process consisting of the following operations (stages): wood cooking into pulp semifinished product (delignification to 3–4% residual lignin content in pulp); pulp bleaching (advanced delignification to ~1% residual lignin in pulp semifinished product); regeneration of reagents; processing of lignin-containing waste; and treatment of gas emissions and wastewater.

The environmental impact exerted by pulp and paper enterprises is due to emissions of gases and discharges of wastewater contaminated with sulfur-containing and chlorinated reagents used in the major processes (cooking and bleaching), as well as with products of their reactions with wood components. The most significant pollutants include hydrogen sulfide, mercaptans, dimethyl sulfide, and other sulfur-containing volatile organic compounds, extractive substances, lignins, phenols, organochlorine compounds, etc.

Liquid waste generated by pulp and paper enterprises appears as a multicomponent aqueous system containing suspended solids, inorganic components, organic components (lignins, phenols and their derivatives, carbohydrates, resin and fatty acids, sulfur-containing and chlorinated compounds, methanol, turpentine, formaldehyde, etc.).

The environmental performance of the mills was assessed using the following priority environmental indicators: COD and $BOD_5$ (chemical and biochemical oxygen demands, respectively) and the content of suspended solids, total nitrogen, and total phosphorus in discharges [1]. The chemical oxygen demand is an integrated index ranking among the most informative indicators of anthropogenic pollution of water. The use of COD as integrated priority indicator was substantiated by the estimated contributions to this parameter coming from inorganic and organic wastewater components, as well as from individual components and groups of organic fractions [9, 10]. The content of suspended solids was determined as the COD difference between the initial and filtered samples of wastewater from OAO "Arkhangel'skii TsBK" at 35–40, 40–43, and 3–9% for wastewater before biological treatment, effluent from stage 1 biological wastewater treatment facility (an increase is due to return sludge), and clarified biologically treated wastewater, respectively.

The organic and inorganic wastewater components were separated by ion (combined cation-anion exchange) chromatography. The inorganic pollutants

**Table 1.** Mass balance of organic constituents of COD for OAO "Arkhangel'skii TsBK" wastewater

| Pollutant | Relative content, %, of pollution constituent | | |
|---|---|---|---|
| | production of bleached sulfate pulp | wastewater before biological treatment | wastewater after biological treatment |
| Lignin compounds | 28.70 | 39.69 | 54.82 |
| Volatile compounds, in particular: | 45.83 | 45.56 | 20.44 |
| volatile phenols | 0.97 | 0.15 | 0.02 |
| turpentine | 1.21 | 0.39 | 0.08 |
| methanol | 9.52 | 6.12 | 6.98 |
| Nonvolatile phenols | 3.10 | 2.06 | 11.00 |
| Neutral substances | 3.30 | 3.60 | 5.50 |
| Resin and fatty acids | 9.91 | 0.97 | 1.21 |
| Oxidized acids | 9.16 | 8.13 | 7.04 |

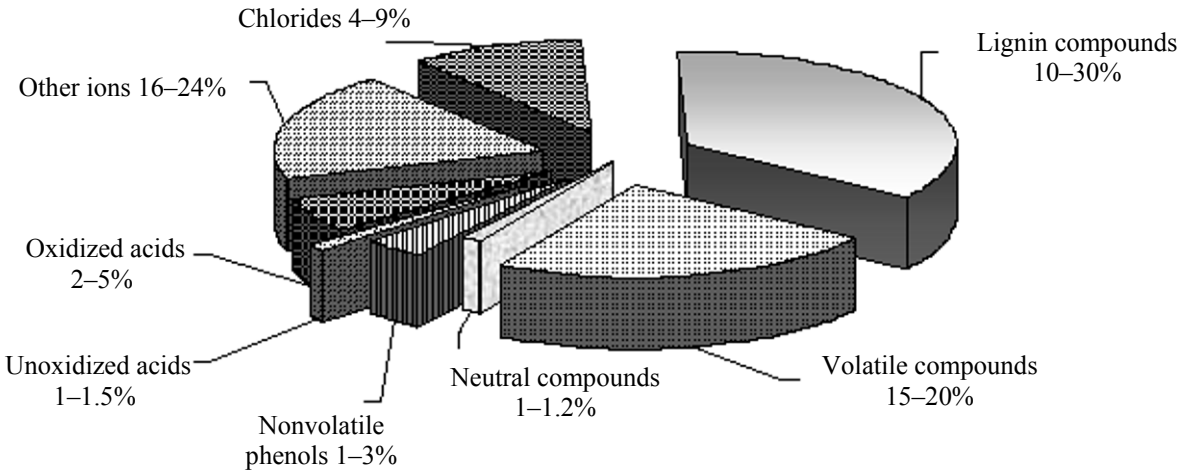


**Fig. 1.** Mass balance for COD of the wastewater before biological treatment at OAO "Arkhangel'skii TsBK."

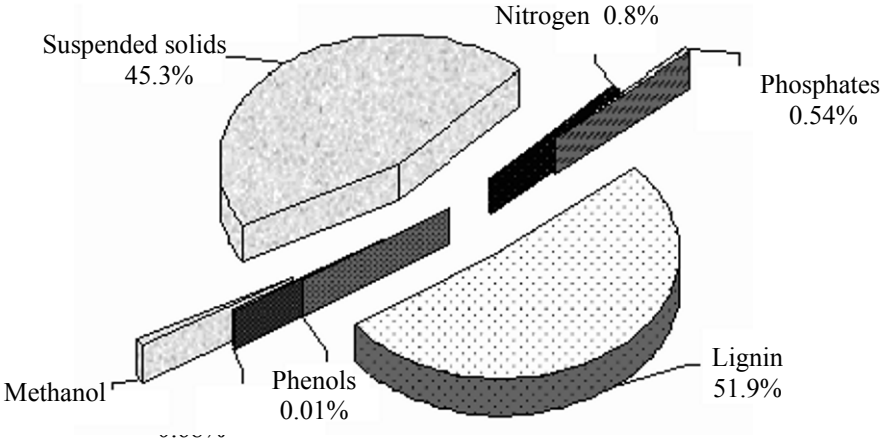


**Fig. 2.** Characterization of the quality of biologically treated wastewater for OAO "Arkhangel'skii TsBK" based on the content of the major groups of pollutants.

contained in the wastewater coming into the biological treatment facility contributed to COD with 30–50%, and those in biologically treated wastewater, with 40–60%.

As to organic pollutants, the largest contribution to COD (up to 80–95% for any type of wastewater) comes from the sum of lignin compounds and volatile pollutants (Table 1 and Fig. 1). For the biologically treated wastewater the contribution from volatile organic pollutants decreases to 20.5%, the relative contribution from the lignin compounds being 35–40 and 55% before and after treatment, respectively.

The total "organic" COD after the biological wastewater treatment stage decreases fivefold, specifically, more than tenfold for volatile compounds and only twofold for lignin compounds. The fraction of inorganic components in biologically treated wastewater contributes to the COD decrease with 10% solely. This suggests a dramatic increase in the relative content of inorganic substances in the effluent entering the dispersal outflow.

Thus, the biological wastewater treatment technology employed at OAO "Arkhangel'skii TsBK" enables efficient assimilation of volatile components; the highest-molecular-weight fraction of lignin components, which represents the hardly oxidizable COD constituent, passes in a "transit" manner through the system (Fig. 2).

Using the COD data obtained, the efficiency of the wastewater treatment technology that is currently employed by OAO "Arkhangel'skii TsBK", was assessed. Specifically, the degree of pollution removal, %, for each group of components was as follows: volatile compounds 80–92, nonvolatile phenols 70–85,

**Table 2.** Content of pollutants in discharges/emissions and energy consumption for sulfate pulp production by Russian pulp and paper mills against those for pulp production based on "best available techniques" (BAT) (there are no carbon monoxide emission standards for pulp and paper mills in European legislation)

| Product | Liquid discharge components, kg (pulp ton)$^{-1}$ | | | | | | |
|---|---|---|---|---|---|---|---|
| | wastewater volume, $m^3$ $ton^{-1}$ | substances | | Suspended solids (TSS) | Organochlorine substances | $N_{tot}$ | $P_{tot}$ |
| | | COD data | $BOD_5$ data | | | | |
| Pulp produced with the use of BAT | | | | | | | |
| bleached | 30–50 | 8–23 | 0.3–1.5 | 0.6–1.5 | <0.25 | 0.1–0.25 | 0.01–0.03 |
| unbleached | 15–25 | 5–10 | 0.2–0.7 | 0.3–1.0 | – | 0.1–0.2 | 0.01–0.02 |
| Pulp (unbleached + bleached), OAO "Arkhangel'skii TsBK" (2008) | 138.3 | 16.5 | 1.2 | 3.1 | <0.25 | 0.3 | 0.03 |
| Pulp products available from OAO "Mondi Syktyvkarskii LPK" (2007/2008) | 92.7<br>87.8 | 18.8<br>18.8 | 1.7<br>1.7 | 2.2<br>2.17 | 0.151 | 0.33 | 0.034 |

| Product | Gas emission components, kg (pulp ton)$^{-1}$ | | | Energy consumption per ton of pulp | |
|---|---|---|---|---|---|
| | sulfur-containing compounds[a] (on sulfur basis) | $NO_x$ (on $NO_2$ basis) | dust (SS) | thermal, GJ | electric, MW h |
| Pulp produced with the use of BAT | | | | | |
| bleached | 0.2–0.4[a,b] | 1.0–1.5 | 0.2–0.5 | 10–14 | 0.6–0.8 |
| unbleached | 0.2–0.4[b] | 1.0–1.5 | 0.2–0.5 | 14–17.5 | 1–1.3 |
| Pulp (unbleached + bleached), OAO "Arkhangel'skii TsBK" (2008) | 0.403/0.392[c] | 0.84 | 3.12 | 14.5 | 0.641 |
| Pulp products available from OAO "Mondi Syktyvkarskii LPK" (2007/2008) | 0.237/0.237[c]<br>0.069/0.053[c] | 1.62<br>4.2 | 4.0<br>2.41 | 16.51<br>16.12 | 1.699<br>1.695 |

[a] Total sulfur content. [b] Total reduced sulfur emission on sulfur basis is 0.1–0.2 kg $ton^{-1}$. [c] For integrated plant producing unbleached sulfate pulp and paper (e.g., liners of corrugated cardboard). Numerator is the total emission of sulfur compounds on sulfur basis, and denominator, reduced sulfur emission on sulfur basis.

resin and fatty acids 56–82, neutral substances 56–65, lignin compounds 50–60, and inorganic components 6–15%. Based on COD indicator, the overall efficiency of the biological treatment was estimated at 40–65%.

With the above-mentioned components present, the wastewater disposal and treatment technology is to be chosen with a view to providing both the mechanical treatment to remove the dispersed phase and advanced biological or chemical oxidation of pollutants.

The discharge/emission levels for priority pollutants were estimated in terms of the integrated priority quality indicators for wastewater and gas emissions generated by individual shops, units, and the whole enterprise against the relevant BAT-based European limits set for pulp and paper industry (Table 2).

In view of the specific features of the pollutants generated in the production process, as well as of the environmental, climatic, and hydrological characteristics of the region of interest, the wastewater and the

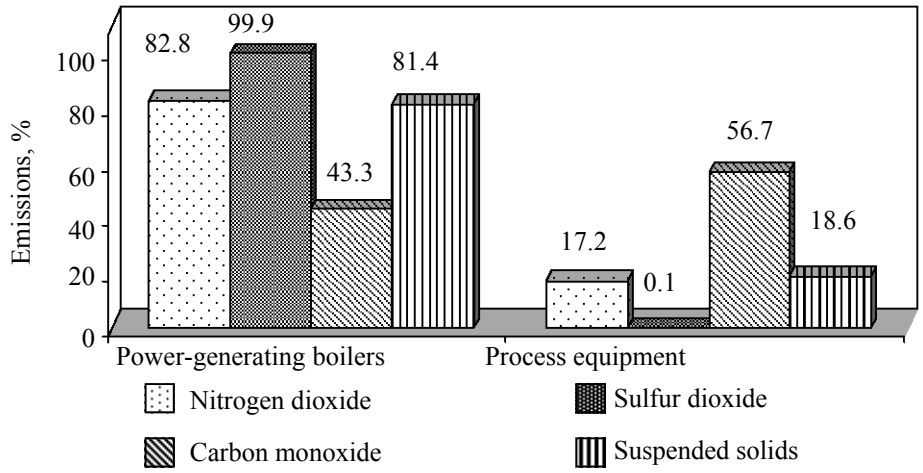


**Fig. 3.** Content of priority pollutants in emissions from the process and power generation equipment at OAO "Arkhangel'skii TsBK" (2008).

receiving water body quality was characterized with the use of an abridged set of indicators. It should be noted that reduction of discharge levels for the wastewater generated by pulp and paper mills (suspended solids, COD, $BOD_5$, total nitrogen, and total phosphorus) in terms of integrated quality indicators will automatically bring the content of other wastewater pollutants down to environmentally acceptable levels.

Comparison showed that, in all the characteristics except for wastewater volume and amount of suspended solids (see Table 2), the pollution discharges for the wastewater from pulp production at OAO "Arkhangel'skii TsBK" and OAO "Mondi Syktyvkarskii LPK", correspond to, or slightly exceed (in the case of $BOD_5$, $N_{tot}$), those at enterprises that employ "best available techniques."

It should be noted that the BAT-based gas emission limits set for pulp production processes apply only to the major process and power generation equipment. The reason is that, according to the European legislation, pulp and paper mills collect and utilize malodorous gases emitted by fugitive sources. In our opinion, it is sufficient to estimate the emissions from the major process and power generation equipment solely. Over the period of monitoring at Russian enter-prises, gas emissions from the rest of the equipment available ranged from 3.5 to 5.5% of the total gas emissions.

The composition and amount of gas emissions generated by the operating equipment are determined by the type of the fuel used by the enterprise.

The fuel types used by OAO "Mondi Syktyvkarskii LPK" in 2008 can be summarized as follows, %: natural gas 72.8, heavy black liquor 21.9, bark waste 5.1, and oil fuel 0.2. The proportion of the materials generated by the mill as fuel (heavy black liquor and bark waste) was 27%. The resulting emissions of carbon monoxide, nitrogen dioxide, suspended solids, and sulfur compounds (on sulfur basis) contributed to the total emissions of these components at the mill with 70.4, 16.8, 9.8, and 2.4%, respectively.

At OAO "Arkhangel'skii TsBK," the contributions from individual fuel types to the overall balance of the fuel spent in 2008 were as follows, %: coal 56.7, waste wood and raw wastewater treatment sludge 8.8%, heavy black liquor 32%, and oil fuel up to 2.5%. The proportion of the materials generated by the mill as fuel (heavy black liquor and bark wastes) was 40.8%. The resulting emissions of suspended solids, carbon monoxide, sulfur dioxide, and nitrogen dioxide contributed to the total gas emissions with 37.7, 9.0, 38.4, and 13.0, respectively.

The contribution from power-generating boilers to emissions generated by OAO "Arkhangel'skii TsBK" in 2008 was estimated at 84.4% (including emissions associated with fuel burnt to generate the heat for satisfying the social needs of the city). Figure 3 shows how individual pollutants contributed to the total gas emission from the major process and power generation equipment.

The process equipment contributed to pollution emissions with 15.6% of the total gas emission, which value is composed of 6.4 and 9.2% accounted for by production of cardboard and pulp, respectively. The reduced sulfur (hydrogen sulfide, methyl mercaptan,

dimethyl sulfide, and dimethyl disulfide) emissions from the process equipment are responsible for 100% of these compounds emitted by OAO "Arkhangel'skii TsBK." The nitrogen dioxide, suspended solids, carbon monoxide, and sulfur dioxide emissions generated by the process equipment contributed to the total emissions of these components with 17.2, 18.6, 56.7, and 0.1%, respectively.

In terms of the total sulfur emissions (on sulfur basis) and nitrogen oxide emissions per unit product weight (on nitrogen dioxide basis), the gas emission level at OAO "Arkhangel'skii TsBK" corresponds to that at the pulp and paper industries that apply "best available techniques" (see Table 2). The reduced sulfur emissions [BAT-based emission limit value is 0.1–0.2 kg (pulp ton)$^{-1}$] need to be decreased by half at the entire mill. The dust levels in the gas emissions from pulp production at OAO "Arkhangel'skii TsBK" exceed more than fivefold the European BAT-based limits set for suspended solids emissions by pulp and paper industries.

At OAO "Mondi Syktyvkarskii LPK", the process equipment is responsible for 100% of the total sulfur emissions which are mainly contributed by soda regeneration boilers and dissolving tanks. The total gaseous and reduced sulfur emissions per unit product weight [0.069 and 0.053 kg (pulp ton)$^{-1}$] in bleached sulfate pulp production correspond to those at analogous European enterprises.

The process equipment and bark boilers at OAO "Mondi Syktyvkarskii LPK" accounts for 100% of suspended solid emissions which are contributed by soda regeneration boilers and dissolving tanks (93.4%), bark boilers (2.1%), and lime regeneration furnaces (4.5%). The total suspended solid emission levels per ton of bleached sulfate pulp exceeded more than fivefold those for European enterprises that apply "best available techniques."

The nitrogen oxide (on nitrogen dioxide basis) emissions per unit product weight at OAO "Mondi Syktyvkarskii LPK", including those from the operating power generation equipment, exceeded the emission level prescribed by the relevant European standards.

As regards thermal and electric power spent for pulp production at Russian enterprises, these data cannot be compared with those for analogous European enterprises, because the relevant European standards apply to specific products manufactured by cardboard- and papermaking machines with specific design characteristics.

Also, the European legislation does not regulate the formation and storage of solid waste materials: They must be either destroyed or utilized.

As prescribed by the acting legislation of the Russian Federation, the industrial solid waste hazards were categorized, certification of hazardous waste was carried out, and a primary accounting system for waste was established.

Given below are the environmental performance assessment data for OAO "Arkhangel'skii TsBK" with respect to hazard class 4 and 5 process waste (hazard class 4 integrates all wood and bark-containing wastes, as well as wastes from water treatment stages, mechanical and biological treatment of wastewater, calcium carbonate sludge, and other wood processing waste, and hazard class 5 includes wood ash, waste pulp fiber, uncontaminated paper and cardboard waste, and paper and cardboard disruption and packaging waste). The monitoring results are expressed in kilograms of waste per ton of bleached sulfate pulp.

The amount of inorganic waste generated by OAO "Arkhangel'skii TsBK" in 2007, 34.6 kg dry weight (kgDW) per ton of air-dried pulp (ADP) [kgDW (APD ton)$^{-1}$], does not go beyond the range set for similar European enterprises [40–70 kgDW (ADP ton)$^{-1}$]; it is somewhat lower because of discharges of green liquor sludge from bleached sulfate pulp production into the production sewage system.

As to organic waste generated in 2007 [74.9 kgDW (ADP ton)$^{-1}$], its amount exceeds the limit value set for similar European enterprises [30–60 kgDW (ADP ton)$^{-1}$], mostly due to the contribution from sludge produced at biological wastewater treatment plants.

Nearly all the large-tonnage industrial waste materials generated by paper and pulp plants are either burned for heat generation or landfilled. The ash contained in solid waste can be utilized in an economically viable manner for manufacture of building materials and artificial fertile soils (combined with biological wastewater treatment sludge) intended for quarry reclamation and road slope arrangement. However, preparation of artificial fertile soils in this case will require additional landfills, whose availability is not always realistic. In our opinion, an economically justified option can be found in joint combustion of excess biological wastewater treatment sludge and bark waste in bark boilers. This will reduce the amount of additional fuel to be spent for heat and power generation at the mill.

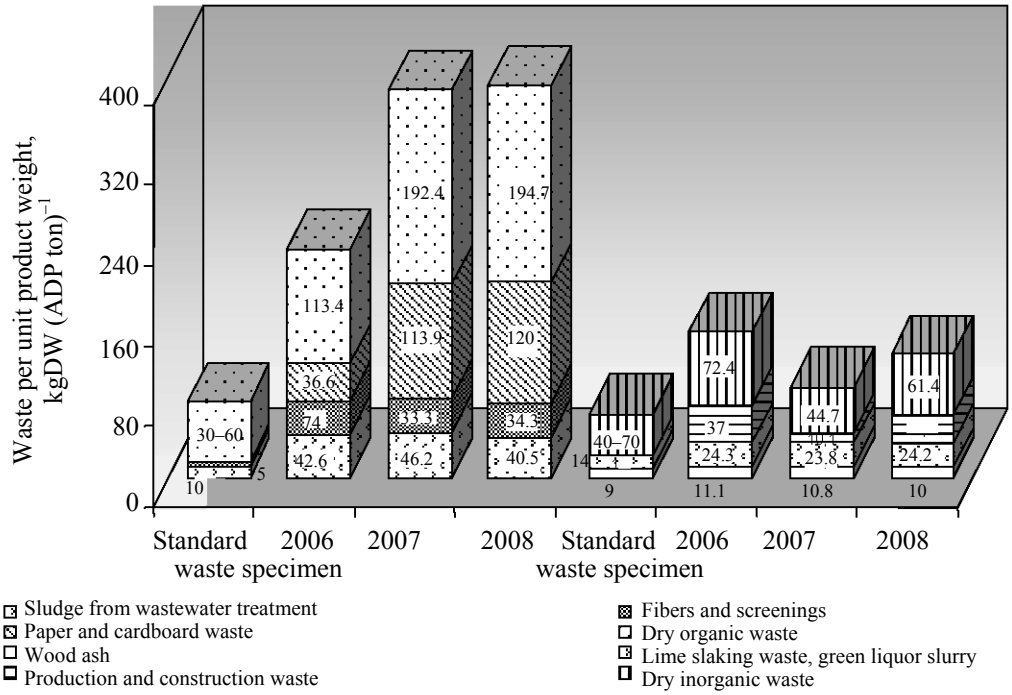


**Fig. 4.** Organic and inorganic process waste generated by OAO "Mondi Syktyvkarskii LPK."

Over the period 2003–2008, the degree of utilization of the process waste at OAO "Mondi Syktyvkarskii LPK" increased from 88.9 to 95.3%. In 2008, 0.5% of the total process waste generated by the mill was landfilled, and another 4.2%, neutralized.

The organic waste materials generated by OAO "Mondi Syktyvkarskii LPK" are accounted for mostly by bark waste products which serve as secondary raw materials and are burned in bark boilers for heat and power generation purposes (Fig. 4). In a similar way, the natural clean chips waste generated by the mill is also burned in bark boilers. Clean paper and cardboard waste is reprocessed into commercial products. Up to 90% of wood waste (twigs and undercooked pulp) is burned in bark boilers, and 10% goes to the grinding stage preceding the processing at a papermaking machine. Garbage is landfilled. The residual solids from primary settlers and excess active sludge are used for slime collector reclamation. Also, biological wastewater treatment sludge can be burned in bark boilers.

As to inorganic waste generated by the OAO "Mondi Syktyvkarskii LPK," its amount lies within the range specified for similar European enterprises.

Our data suggest that the large-tonnage process waste generated by the pulp and paper mills is virtually entirely used for slime collector reclamation.

Based on integrated assessment and analysis of environmental performance of two large pulp and paper mills it is possible to formulate the main principles of designing a scheme for eco-analytical control of discharges/emissions and specify the options to reduce the environmental impact they exert.

The eco-analytical control of wastewater generated by pulp and paper mills should be based on the use of a priority integrated index whose selection will require identification of the (essential) priority pollution constituents and assessment of their contributions to the total COD.

There is a need in development of standards regulating the consumption levels for water used in manufacturing of pulp products by forest industries. The European legislation treats this water as being intended to satisfy the process needs solely, with the water consumption for technical needs (gland sealing etc.) being neglected. Russian enterprises keep records of the water use and consumption starting from the water supply to an enterprise from a water source. With thermal power stations available at many of the Russian enterprises, there is a need in a uniform water consumption standard for integrated enterprises, which will take into account possible water recycling and local wastewater treatment schemes aimed at water reuse in the process cycle [11–13].

A decrease in the amount of biological wastewater treatment sludge can be achieved via reduction of the pollution levels for the water subjected to biological treatment. This will require undertaking certain organizational and technical, as well as technological activities. The organizational and technical activities will include more complete collection of all the leaks and sinks of black liquor during discharges of pipes and equipment before repairs and washings to be followed by evaporation and concentration of the fluids collected. An example of the technological activities can be found in the use of filtrates from the bleaching stage and of other wash waters after being locally treated in the process cycle. Also, there is a need to reduce the water consumption by paper- and cardboard-making machines, and, certainly, to prevent the discharges of slime water to the process sewage system. These measures will lead not only to reduction in the sludge generated but also to a decreased amounts of inorganic compounds contained in the sludge and its higher calorific value.

A separate block will integrate technological solutions aimed at thermal and electric power conservation. To this end, each facility manufacturing a finished product is to be surveyed with due regard to the specific design characteristics of paper- and cardboard-making machines.

As regards emissions of malodorous reduced sulfur compounds, their reduction can be achieved via collection and utilization of all gas emissions from sources (liquor collectors, major equipment, and environmental facilities), as well as via improvement of the efficiency of gas scavenging systems, soda regeneration and bark boilers, and lime regeneration furnaces. The collection technology for malodorous emissions generated by the major equipment and environmental facilities is already implemented at OAO “Mondi Syktyvkarskii LPK”; the emitted materials are burned in a specially arranged boiler.

## REFERENCES


1. *Directive 2008/1/EC of the European Parliament and of the Council*, January 15, 2008. Concerning Integrated Pollution Prevention and Control, Official Journal of the European Union, L 24, January 29, 2008, p. 8.
2. *Federal Act On Amendments to Selected Legislative Acts of the Russian Federation (Relevant to Improvement of Environmental Regulation and Introduction of Economic Incentives for Implementation of Best Available Techniques by Business Entities)*, Draft Version, March 25, 2010.
3. Lichutina, T.F., Tsyganov, S.P., Gusakova, M.A., and Miskevich, I.V., *Tsellyuloza. Bumaga. Karton*, 2008, no. 7, p. 70.
4. Lichutina, T.F., Vishnyakova, A.P., Gusakova, M.A., Beloglazov, V.I., and Soboleva, T.V., *Tsellyuloza. Bumaga. Karton*, 2008, no. 7, p. 65.
5. Lichutina, T.F., Gusakova, M.A., and Vishnyakova, A.P., *Tsellyuloza. Bumaga. Karton*, 2009, no. 3, p. 69.
6. Lichutina, T.F., Tsyganov, S.P., Gusakova, M.A., and Vishnyakova, A.P., *Tsellyuloza. Bumaga. Karton*, 2009, no. 5, p. 63.
7. Lichutina, T.F., Gusakova, M.A., and Vishnyakova, A.P., *XV Vserossiiskaya konferentsiya s mezhdunarodnym uchastiem “Geologicheskie opasnosti”* (Russian Conf. with Participation of Foreign Specialists ”Geological Hazards”), Arkhangel’sk, September 14–17, 2009, p. 281.
8. Lichutina, T.F., Miskevich I.V., Brovko, O.S., and Gusakova, M.A., *Optimizatsiya normirovaniya sbrosa stokov predpriyatii TsBP v vodotoki* (Optimization of Regulation for Effluent Discharges into Watercourses by Pulp and Paper Mills), Yekaterinburg: Ural. Otd. Ross. Akad. Nauk, 2005, ISBN 5-7691-1637-4.
9. Pochtovalova, A.S., *Cand. Sci. (Chem.) Dissertation*, Arkhangel’sk, 2002.
10. Soboleva, T.V., *Cand. Sci. (Tekh.) Dissertation*, Arkhangel’sk, 2007.
11. Smirnov, M.N., Lokshin, Yu.Kh., Smirnov, A.M., and Akim, E.L., *Tsellyuloza. Bumaga. Karton*, 2006, no. 6, p. 6.
12. Smirnov, A.M., Smirnov, M.N., Moshkin, S.S., Kovalenko, M.V., and Akim, E.L., *Tsellyuloza. Bumaga. Karton*, 2008, no. 8, p. 66.
13. Proshkin, K.M. and Goncharov, E.A., *Tsellyuloza. Bumaga. Karton*, 2009, no. 1, p. 68.