Extrusive technology for chemical-thermomechanical pulp from plant raw materials

I N Koveninsky*, V M Gedjo, V K Dubovy, V N Krylov and K D Prokopenko

Innovation Center for Engineering of Processing of Low-Quality Wood and Wood Waste, St. Petersburg State Forest Technical University named after S.M. Kirov, Institutsky Lane, St. Petersburg 5194021, Russian Federation

*Corresponding email: kovern@list.ru

Abstract. In the article, the possibility of highly profitable and environmentally safe processing of low-quality wood and wood waste by low-tonnage plants using extrusion technology has been substantiated. The basics of the technology for the production of extrusive thermomechanical wood pulp (ETMP) with the use of chemicals are given, and the main specific costs of wood, chemicals and energy resources are provided. The limits of the main quality indicators of ETMP are provided, which are important for its widespread use in the production of paper and cardboard. The extrusive technology for processing of raw materials into fiber is economically viable. The target product is obtained from wood with a yield of 85–80%, and from straw, of 75–60% of the mass of raw materials; profitability is in the range of 25–50%; production creation time is 1.0–2.5 years, depending on productivity (20, 50, 100 and 200 tons per day), and the return on investment is 2-3 years. The advantages of technological lines for processing wood and straw are compactness, ease of installation, and relatively small production areas. The extrusion technology is promising for the processing of waste from forestry enterprises, and is recommended for use in Russia.

1. Introduction

The main renewable and inexhaustible raw material resource of forests is wood, and sawlogs remain the main object of harvesting and processing. Both processes are accompanied by accumulation of wood by-products – pulpwood and sawn timber cutting waste – in volumes significantly exceeding the yield of the target product (sawn timber).

Irrational use of wood resources, especially in terms of processing of low-quality deciduous wood and logging and sawmill waste required the adoption of the long-overdue "Strategy for the development of the forest complex until 2030" [1]. It provides the following indicators for increasing the output of the pulp and paper industry:

- commercial cellulose, by 5.7 million tons/year;
- sanitary and hygienic products, by 0.4 million tons/year;
- packaging paper and cardboard, by 0.26 million tons/year;
- writing paper, by 0.45 million tons/year;
- the export of cellulose, by 8.3 million tons/year.

The above goals can only be achieved on condition of a corresponding increase in the production of pulp and paper. However, sources of the formation of huge wood raw material by-products – timber industry enterprises – have so far been deprived of the technological opportunity to take full advantage
of the high profitability of processing raw materials into pulp and paper fibrous semi-finished products (PPFSFP). The objective reason for this state of affairs is the lack of production of equipment for organizing, parallel to the main one, technological lines for processing by-product into pulp and paper, at Russia’s timber processing enterprises; the following conditions should be satisfied:

- productivity, corresponding or close to the volume of accumulation of by-product raw materials by an individual or a group of closely located timber processing enterprises;
- the demand for pulp and paper;
- commensurability of investments in the creation of a technological line with the investments of the created new main sawmill production;
- environmental safety and prevailing profitability of pulp and paper production over alternative production that does not use chemical reagents.

A promising solution to the problem is the leadership of the Strategy [1], which provides for state support for deep chemical processing of wood and extrusive technology for processing wood into extrusive thermomechanical pulp using chemicals (ETMP) on the production lines of Chinese engineering plants.

Production lines which satisfy the above conditions are produced at a capacity of 30, 60, 100 and 200 tons per day and provide a fundamental possibility of building a plant (workshop) for one or a group of enterprises [2].

2. Material and Methods

The production of ETMP (unbleached and bleached) involves a high degree of wood conversion (deep chemical processing of wood). For the processing of wood and any other plant raw materials (straw of cereals, flax and hemp, etc.), extrusion technology is proposed [3]. The pre-treated raw materials (wood chips, chopped straw) are subjected to a simultaneous multifactorial treatment with transformation into fibrous mass. A feature of the preparation of wood chips is impregnation with alkali under normal conditions or at low (up to 80 °C) temperatures without atmospheric pressure. The resulting mass is subjected to sequential grinding; first, in two or three stages in disc refiners at a high mass concentration, and then in two or three stages in disc refiners with an average concentration in the mass of the required degree of grinding (30–40 °SR). Further, the mass can be used in a liquid stream for the production of paper (cardboard) at a given enterprise, or dried to a marketable product (moisture content of 10%) and sold on the market.

As mentioned above, technological lines are based on a new extrusion technology that has not yet been used in Russia. The main piece of machinery used is a multifunctional twin-screw extruder, due to which the technology is fundamentally different from the classical ETMP production method. Many industrially valuable wood species are suitable for the production of pulp with the yield of 80–85%, and the consumption of raw materials, depending on the wood density, is within 2.5–3.5 m³/t mass.

The presence of a twin-screw extruder, rational selection and placement of the main equipment of the technological line, provides a number of advantages:

- the process of chip preparation additionally includes the stages of chip aging in atmospheric conditions (at least 1 month) and alkaline impregnation under normal conditions or temperatures up to 80 °C;
- multifunctional treatment of wood chips, including chemo-, thermo- and mechanical, is carried out in an extruder at the atmospheric pressure, accompanied by a decrease in power consumption by up to 40%, and ends with the release of the target product, fiber mass, and waste;
- the grinding of chips in the extruder proceeds at a low hydromodule, up to two, which makes it possible to grind the fibrous mass into fiber in disc refiners at a high concentration, 34–37%, and after dilution, at an average concentration of the mass of 6–9 %;
- combination of washing and dehydration of the mass either in a belt press, or sequentially in a belt press and auger press; mass moisture content is 37–40% with the possibility of drying to a final moisture content of 8–10% in compact and highly efficient aerodynamic dryers;
• pressing the finished mass into briquettes of high density, 750–850 kg/m³, which significantly reduces transportation costs;
• there is no regeneration of chemicals and multistage washing of the mass, and, therefore, no need to use a large volume of water, purify its excess and discharge into water bodies; the water used is in the circuit, and the losses are compensated for by fresh water;
• the use of sulfur-free chemicals and low-temperature cooking (85–90 °C) ensures the absence of foul-smelling gas emissions;
• the advantages of the technology make it possible to classify it as environmentally safe.

3. Results and Discussion

3.1. ETMP quality
The first stage of chip grinding in a twin-screw extruder has a positive effect on the pulp grinding characteristics. As a result of high-frequency "compression-decompression", wood tissue is split mainly along the cells. This mechanism allows maintaining the original cell size, the prevalence of the long-fiber fraction, and good surface activity of the fiber [4–6].

This technology is used to produce unbleached and bleached ETMP, which are popular products for the production of paper and cardboard. Table 1 shows the limits of the main standardized quality indicators of ETMP that can be achieved when processing deciduous and coniferous wood.

Table 1. The main indicators of ETMP from deciduous and coniferous wood.

| Indicators                          | Indicator value |
|------------------------------------|-----------------|
| The output from the mass of a.d.w., % | 85–80           |
| Grinding degree, SR                | 30–40           |
| Whiteness, %                       | 20–25           |
| Breaking length, km                | 3.0 – 4.5       |
| Contamination, mm²/300 g           | 50–100          |
| Dryness, %                         | 37–40 or 90–92  |
| pH                                 | 8.0             |

The analysis of quality indicators characterizes ETMP as a promising fibrous material for use in the production of many types of paper and cardboard.

A study of the fractional composition of ETMP by fiber and fiber microscopy were carried out. Fractional composition was investigated at two degrees of grinding, 18° and 40°SR on the device "Fibertester". The research results are shown in tables 2 and 3.

Table 2. Fractional composition of ETMP by the fiber length.

| Length ranges, mm | The share of fibers in the total mass, % |
|-------------------|----------------------------------------|
|                   | ETMP 18 | ETMP 40 |
| 0.20 – 0.53       | 17      | 21.3    |
| 0.53 – 0.85       | 32.9    | 34.9    |
| 0.85 – 1.18       | 33.8    | 30.9    |
| 1.18 – 1.5        | 13.5    | 10.5    |
| 1.0 and above     | 2.9     | 2.5     |

The results show that the fraction of medium- and long-fiber mass accounts for 83.1% of ETMP at a grinding degree of 18° SR and 78.8% at a grinding degree of 40°SR. The fraction of fine fiber, fraction 0.20–0.54 mm, is 17.0 and 21.3%, respectively. The addition of a fraction of fine fiber when grinding the mass from 18 to 40°SR is 4.3%. The results of microscopic examination of ETMP are shown in figure 1.
Table 3. Fractional composition of ETMP by the fiber width.

| Width ranges, μm | The share of fibers in the total mass, % |
|------------------|-----------------------------------------|
|                  | ETMP 18 | ETMP 40 |
| 5.0 – 16.0       | 13.9    | 14.1    |
| 16.0 – 28.0      | 41.4    | 39      |
| 28.0 – 39.0      | 28.8    | 31.6    |
| 39.0 – 50.0      | 10.1    | 9.8     |
| 50 and above     | 5.8     | 5.4     |

Figure 1. Micrographs of ETMP.

The micrographs clearly show the characteristic deciduous wood fibers: libriform fibers and core rays (thin and long), and vessels (short and thick). The fibers remain almost unchanged (slightly damaged), retain their length and high surface activity for the formation of interfiber bonds. The mechanism of separation predominantly along the wood cells is visually confirmed (layer S₁).

The length of the fiber and the degree of grinding directly affect the physical and mechanical properties of paper (cardboard). The longer the fiber and the greater the degree of grinding according to the mode of predominantly fibrillation of the fiber surface, the higher are the physical and mechanical parameters. A number of them are presented in table 4.

As it can be seen from table 4, the physical and mechanical parameters of the ETMP correspond to the values for this type of pulp and paper. Therefore, the mass is suitable for use in paper and paperboard compositions. In compositions, it can consist 30–100%.

Table 4. Physical and mechanical properties of ETMP.

| Weight | Breaking length, m | Resistance punching shear, kPa | Resistance to tearing, mN |
|--------|--------------------|--------------------------------|--------------------------|
| ETMP, at 59°SR | 4800               | 155.0                         | 308.0                    |
3.2. Basic data on ETMP plants
Conditioned chips, after aging in atmospheric conditions, are fed by a loader into a metering hopper dosing chips into the technological process in the amount of 1.2 t/t of a.d.m. First, the chips are dry cleaned (small organic and inorganic particles are separated, including dust). Waste is generated in amount 0.024 t/t a.d.m. Then the chips are wet cleaned (rinsed with water). Waste is generated in amount 0.012 t/t a.d.m. In total, waste is generated at the chip cleaning stage in amount of 0.036 t/t a.d.m. Waste is a liquid mixture of wood particles and dirt that must be disposed of in a dump.

Contaminated water from chip washing is cleaned and returned for washing. Water losses during the washing process are replenished with fresh or recycled water from other processes of the technology.

Refined wood chips in the amount of 1.164 t/t a.d.m. are sent for steaming and impregnation with chemicals (mainly NaOH) sequentially into impregnating screws (2 pcs.), and then blanching screws (2 pcs.) are sequentially passed. In the blanching screws, the chips are held in order to deepen the impregnation with chemicals. In the process of steaming, steam is used at a pressure of 2-3 atm., and temperature of 120–130 °C, in amount of 0.2–0.3 tons of steam per 1 t on a.d.m.

The wood chips aged in the blanching screws continue to mature in the softening hopper, in which the process of impregnation and chemical interaction of wood components and chemicals is completed.

In the process of impregnation, blanching and holding in the softening hopper, chemical reactions occur in the chips, the result of which is a partial dissolution of wood, approximately 0.093 t/t a.d.m. This liquid part of the waste together with a part of solid wood waste (approximately 0.06–0.08 t/t a.d.m.) is separated in the extruder. The solid part of the waste is returned to the extruder, and the liquid part is utilized in the technology.

The bulk of chips from the softener hopper in the amount of 1.071 t/t a.d.m. is ground in an extruder into a fiber-bonded pulp (FBP). Part of the chemicals (hydrogen peroxide, liquid glass) are added during the grinding process.

From the extruder, 1.071 t FBP/t a.d.m. enters to the bunker-reactor, in which it slowly moves for grinding successively in the 1st, 2nd and 3rd refiners of high concentration (30–32%). Progressing through the reactor provides a deepening of the reaction of the FBP with chemicals. In refiners, FBP is ground (defibrilated) into coarse fiber. Between the mills, chemicals are still fed into the fiber (additional chemicals) and the fiber enters the tower reactor, where the reactions of chemicals with wood deepen. At the stage of grinding at a high concentration, the wood is split into fibers without surface fibrillation of the fiber (the formation of the smallest fibers on the surface of the fiber - fibrils).

Further, the fiber enters the holding tank, in which it is diluted with water to a concentration of 6–9% and slowly goes for grinding sequentially in the 1st, 2nd and 3rd disc mills of medium concentration. In the tank, the fiber is diluted with circulating water from the belt thickener (belt press). It is necessary to maintain a temperature of 70–80 °C in the tank, which accelerates the process of removing mechanical stress in the fiber (removing fiber latency).

When grinding, the fiber is fibrillated to the required quality and, at a given concentration, is sent to the tank of the finished mass, and from there to the belt press. In it, the fiber is thickened to a moisture content of 33–37%. With water, 0.071 t of fiber/t a.d.m. leaves the belt press. The water is collected in the recirculated water basin, stripped of most of the fiber (90%) and reused to dilute the stock in the waiting tank. The amount of circulating water is 14–15m³/t a.d.m. The amount of returned fiber is 0.064 t, and the loss of fiber (waste) is 0.007 t/t a.d.m.

If a commercial EHTMM is produced, then after the belt press the mass is dried from 33–37% to dryness of 90–92%. Dryers of various designs are used for drying. The highest quality of drying is achieved in aerial drying plants. If paper is produced, then the mass with a dryness of 33–37% is dosed into the composite pool of the paper machine.

Chemicals are prepared in reactors, from which they are pumped into supply tanks, and from them are dosed into the technological process (a complex of 6–8 chemicals).
A total of 0.52 t/t a.d.m. of waste is generated. Of these, 0.50 tons are organic matter (wood origin) utilized in the technology, and 0.02 t/t a.d.m. are various inclusions of mineral origin. They are disposed of by waste collection and disposal companies. The main specific resources for the production of 1 ton of ETMP are presented in Table 5.

| Description | Unit of measurement | Standard value |
|-------------|---------------------|----------------|
| Wood raw material: | | |
| a) pulp wood: aspen, spruce, pine, birch | t | 1.5 |
| b) conditioned chips | t | 1.2 |
| Fresh water: | | |
| a) fiber production | t | 3–5 |
| Chemicals (total) | thousand rubles | 8–10 |
| Electricity: | | |
| a) capacity per production line | MW | 1.7–2.0 |
| a) the cost of fiber production | kW/h | 650 |
| Heat energy: | | |
| a) used in fiber production (drying): | Gcal | 1.2 |
| either air 200 °C, or steam 13 MPa | |

3.3. Project implementation

Project implementation is expedient in two directions:
- at operating forestry enterprises, where the available infrastructure, water and energy resources can be used to the maximum extent;
- at newly created timber industry enterprises, by equipping them with production lines for sawmilling and ETMP.

Approximate indicators of the implementation of investment projects for factories of various capacities are presented in Table 6. The economic results are presented in Table 7.

| Main indicators | Value |
|----------------|-------|
| Productivity, t / day | 30 | 50 | 100 | 200 |
| The need for raw materials, m³ / g | 10 000 | 17 000 | 34 000 | 70 000 |
| Investments, mln. US $: China / general | 1.0 | 1.5/2.5 | 3.0/5.0 | 5.0/10.0 |
| Creation time, years | 1.0–1.5 | 1.0–1.5 | 1.5–2.0 | 1.5–2.0 |
| Required area, m² | 2 000 | 2 500 | 5 000 | 7 000 |

Table 7. Expected economic indicators of production.

| Parameter | Value |
|-----------|-------|
| Sales China, Russia | |
| Expected cost, thousand rubles / t | 12–20 |
| Calculated: for chemistry in total, 5–8 thousand rubles / 1 ton | |
| Expected profit, thousand rubles / 1 ton | 10–20 |
| Expected payback, starting from start-up and reaching production capacity | 2.5–3.0 years |

4. Conclusions

Low-tonnage plants for chemical and mechanical processing of wood by-products into fiber for paper and cardboard production are alternatives to other methods of disposal of waste and low-quality wood. Factories are distinguished by high profitability, environmental safety, and ease of construction and operation.
Factories can be created in the form of separate structural divisions (workshops) as part of timber industry enterprises or in the form of independent production lines.

Factories can generate significant additional profits equal to or exceeding the profits of the main product, sawn timber.

Extrusion fiber can be used in many types of paper and cardboard including packaging (test liner and fluting), box and printing cardboard, filter paper and cardboard, tissue paper, and writing and printing paper. In the composition of these paper and cardboard product types, the fiber can comprise from 30 to 100%.

Multipurpose use of the fiber is explained by its valuable properties: increased rigidity and high light scattering, which is not inherent in a number of other pulp and paper products.

Extrusive technology for processing raw materials into fiber is highly economical. The target product is obtained from wood with a yield of 85–80%, and from straw, of 75–60% of the mass of raw materials; profitability is in the range of 25–50%; production creation time is 1.0–2.5 years, depending on productivity (20, 50, 100 and 200 tons per day), and the return on investment is 2–3 years.

In general, production facilities discussed are full-fledged plants, but of low capacity; they are affordable in terms of raw materials, energy and monetary resources and can be used by many enterprises of the forest and agro-industrial complex of the Russian Federation.

The authors believe that a new extrusive technology for processing plant raw materials into fiber for paper and cardboard will be in demand.

References
[1] Order of the Government of the Russian Federation of February 11, 2021 No 312-r Strategy for the development of the forestry complex of the Russian Federation until 2030 (Moscow)
[2] Zibo Jepps Trading Co. Ltd. 2018 Equipment for the preparation of pulp and paper pulp wastewater treatment equipment (Zhangdian)
[3] Koverninsky I N and Prokopenko K D 2019 Small-scale plants for processing pulpwood and sawmill waste into a highly profitable chemical-thermomechanical pulp for paper and cardboard Forest Complex 2 pp 64–69
[4] Koverninsky I N 2019 Research of physical and mechanical properties of chemical-thermomechanical mass from poplar wood Chemistry of Plant Raw Materials 2 pp 305–310
[5] Koverninsky I N, Prokopenko K D, Dubovy V K, Krinitsin N A and Suslov G A 2019 Investigation of paper based on bleached chemical-thermomechanical pulp from poplar wood Bulletin of St. Petersburg Forest Technical Academy 226 pp 162–170
[6] Prokopenko K D and Koverninsky I N 2018 Investigation of the properties of wood fiber obtained by twin-screw extrusion technology for use in the production of paper and cardboard Proc. Int. Sci.Conf. of young scientists, specialists in the field of the pulp and paper industry, dedicated to the memory of V.A. Chuiko, St. Petersburg, November 12, 2018 (St. Petersburg) pp 107–112