RECYCLED ALGAE PAPER DENSITY CONTROL SYSTEM FOR QUALITY SCREENING WITH ADJUSTABLE LIGHT SOURCE WAVELENGTH

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Abstract. One of the biggest challenges in paper recycling is to ensure even density over the entire area of the sheet. The result is influenced by several parameters: 1) the technology used to prepare the pulp, 2) the equipment, especially the pulp feed mechanism and levellers, 3) the raw materials, such as pulp, its substitutes and, in the case of recycled paper, fillers. A common control method is to scan a sheet of paper against a light source. In this way, changes in density in one sheet can be detected and changes in density of paper pulp can be visually assessed. However, this is not enough for automated production, where information needs to be stored to control the quality of many sheets or large areas of paper, as well as to provide feedback to automated line executives. In a small laboratory environment, numerical quality control makes it possible to objectively compare the design results with changed initial parameters: pulp concentration, raw material fineness, application thickness, smoothness, temperature, etc. For fine quality control, a wide range of visible light wavelengths can provide information. In a situation where the longitudinal dimensions of the fibres are in the order of 10-200 μm, their cross - section is comparable to the wavelength of the light used. In this case, the difference between the sheet scans at 420-450 nm (blue light) and 680-720 nm (red light) shows the proportion of fine fractions in the soft pulp used, which in turn causes changes in the physical parameters of the resulting paper (abrasion resistance, tensile strength, water resistance). Our device allows to automatically measure the differences in the intensity of transmitted light at different wavelengths, which allows us to draw conclusions about the compliance of the applied parameters with the expected result.

Keywords: recycled paper, quality control, light absorption.

Introduction

Plant-based composite materials at present have many advantages. For example, they have low density, high specific properties, are biodegradable, are derived from renewable resources, have a small carbon footprint, and provide good thermal and acoustical insulation.

Natural fibers are mainly obtained from lignin, pectin and waxes, hemicellulose, and cellulose [1]. Classification of nature based “vegetable” fibers includes fibers from: cotton, kapok, milkweed, coir, flax, hemp, jute, ramie, kenaf, pineapple, abaca, henequen, sisal, wood, wheat, maize, barley, rye, oat, rice, bamboo, bagasse, esparto etc. [2; 3]. However, none of the classifications considered by the authors includes algae as natural fiber source.

Most common used nontraditional production fibers are: kenaf (Hibiscus cannabinus) for rope and paper production [4], hemp (Cannabis sativa) used for rope, textiles, garden mulch, the assortment of building materials and animal beddings. Nowadays to fabricate different composites [5; 6], nettle (Urtica dioica) is used for the textile industry, bioenergy, animal housing, etc., attempts have been made to use the nettle fibers on an industrial scale [7; 8].

Different quality control options for composite materials that are made from natural materials are important, because naturally biodegradable composite materials are different from synthetic fibers and fibers that are made from petroleum products. Natural materials differ in geometric, mechanical, thermal, and structural properties. The growth conditions of the plant, climatic conditions, methods of treatment of plant fibers affect its chemical composition as well as the fiber structure, which changes the properties of the composite material made from the plant.

Properties of fibers and their dependence on the chemical component also is in consideration.

Materials and methods

Washed out red seaweed *Furcellaria lumbricalis* from the coast is one of Latvia’s underutilized natural resources. Algae have a wide range of applications in various sectors of the economy. Algae are used in agriculture, in food production, animal feed, cosmetics (thalassotherapy), pharmacy, algae are being studied for use for biofuels (bioethanol, biodiesel, biogas) and biochemicals (pigments,

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biologically active compounds, etc.). Of the more than 10,000 species of coastal algae, about 200 are farmed, but about 10 are intensively farmed [9].

The possibilities of growing macroalgae in the Baltic Sea are currently being intensively studied [10; 11].

Among the algae species found on the Latvian coast, the most economically important are the red alga *Furcellaria lumbricalis* and the brown alga *Fucus vesiculosus*. Furcellaria has been known as a raw material since the 1940s for the preparation of the hydrocolloid furcelaran (food additive E407). Bladderwort *Fucus vesiculosus* is an edible alga [12]. In the 1970s, *Furcellaria lumbricalis* was called *Furcellaria fastigiata* and the hydrocolloid obtained from it was called agar (so-called 'Danish agar'). The amount and composition of algae leached on the shores of the open sea of Kurzeme varies widely, red algae and furcellaria predominate [13]. The leached algal biomass usually contains mixed algal species and impurities that significantly reduce their value [14], however, interest in their economic use has been growing recently [15]. The simultaneous use of leached algae helps reduce the eutrophication of coastal waters, especially with nitrogen and phosphorus [16].

Until the 20th century, in the 1990s, hydrocolloid was obtained from washed out furcellaria in Latvia "Agar" (furcelaran) collective farm "Future", Gluda, Dobele district. Estonia is one of the few countries where furcellaria hydrocolloid is still used [17]. Seaweed detritus is washed ashore and is often considered as waste on the beach of Liepaja municipality. The municipal administration of Liepaja recognizes it as a disturbance, according to approximate estimates, 3717 m^3 of algae waste material has been transported from the Liepaja coast per year and removal costs are 24795 EUR [18]. This dead biomass could be interpreted not as an unwanted material but as a resource in, for example, paper production.

In Latvia, a law was adopted to reduce the consumption of plastic-containing products, which prohibits placing on the market certain plastic articles from 3 July 2021, as well as lays down measures to reduce their consumption [19]. The regulatory framework facilitates the transition to a circular economy with innovative and sustainable materials, thus also contributing to the efficient functioning of the internal market.

In situations where the size of the obstacle is comparable to the wavelength of light, the phenomenon of diffraction occurs. Its definition is well known – due to the wave nature of light, the phenomenon of deviation from the laws of light propagation of geometric optics, which occurs when light passes through a medium with sharp optical inhomogeneities.

As a result, if the size of the obstacle is less than the wavelength, a light wave "wraps" around it and no shadow of the obstacle is formed. It is more complicated in cases where the environment is formed not only by the composition of fibres and voids, but also by a semi-transparent filling with a lower refractive index, then the path of light rays is not straight, but it cannot be called the diffraction effect.

The developed device is based on the improvement of a well-known device – a device for the control of a semi-transparent substance by means of transmitted light. Such screening allows to visually assess the optical density distribution of a thin substance and thus control the quality of the produced sheet. The difference in transparency is directly related to the quality of the pulp mill, the fibre size layout and the uniformity of the pulp layout. In addition, the paper industry is characterized using white light for sheet scanning, which is good enough for visual quality assessment with traditional paper raw materials – wood pulp and/or waste paper. In our device, it is possible to change the wavelength of light, because of which it is possible to estimate not only the thickness of the applied mass, but also to see areas with different fibre grinds and uniformity of arrangement.

Dimensions of the quality control device are 400 mm in length, 300 mm in width and 135 mm in height. The device is equipped with 9 SMD5050 RGB LED strips inside the box with equal intervals throughout 282 mm inside the box. The arrangement between segments of the LED strips is in checkerboard formation to ensure equal light coverage. LED strips and the microcontroller with the help of the voltage regulator module to ensure 5V power for the microcontroller, are powered by a 12-volt power supply. For the functionality the microcontroller is equipped with a HC-06 Bluetooth module to be used to pair with an Android smartphone, Bluetooth Electronics application by Keuwlsoft is used to control the LED strips with the help of IRF540N Logic level N-Channel MOSFETs, sending pulsewidth-modulation (PWM) signals to the gate, and control how much power passes between the drain and the source. By passing each of the LED strip's colors signals through the MOSFET, control of brightness of each individual color on the LED strip is achieved.

In order for the light box to change its color an Android smartphone needs to download the Bluetooth Electronics application. Once the application is installed, the user needs to connect to the Bluetooth module attached to the Arduino Pro Mini microcontroller. With the connection established the user must navigate to the "LED Brightness" panel and run the selected panel, by moving the sliders the application sends a serial message that the Arduino serial port waiting, the messages are started with a character designated for each LED color R, G or B, and an integer value ranging from 0 to 255 acting as a PWM signal strength value for IRF540N MOSFETs and an end message char. With 256 colors available for each channel the total combination of colors is over 16M.

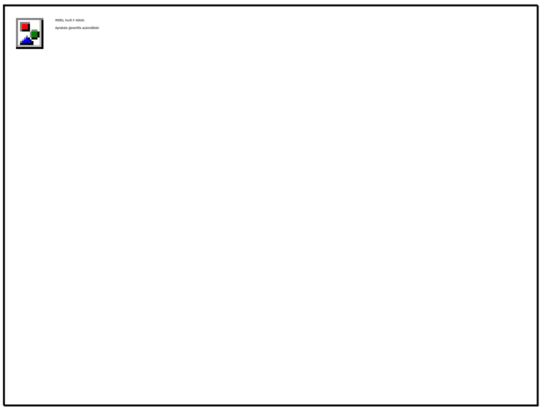

Fig. 1. **Light box in action, grayscale**

The special need for such a developed device (Figure 1) arises from the use of non-traditional raw materials for paper production, such as the seaweed *Furcellaria lumbricalis*. Algae fibres have a different diameter over a wide range, their structure is very different from wood cellulose fibres. The length of the fibres can range from 1-10 μm to 1000 μm and more and the diameter from 200-500 nm to 10 μm and more. To a large extent, it is the uniformity of the pulp mixture that determines the physical properties of the paper, such as tensile, bending and torsional strength. Areas with higher concentrations of small or large fibres impair the resulting physical properties of the paper.

Results and discussion

Figure 2 shows a SEM photograph of recycled paper with fibres of the seaweed *Furcellaria lumbricalis* on the surface of the paper. The length of the fibres varies widely, the distribution of fibres of different sizes is even. A close-up of a medium-sized algal fibre is shown in Figure 3, with a fibre cross-section in the centre of about 20-25 μm, which is a much larger size than the wavelength of light in the optical range. Fibres of this size are clearly visible and form a shadow when exposed to light.

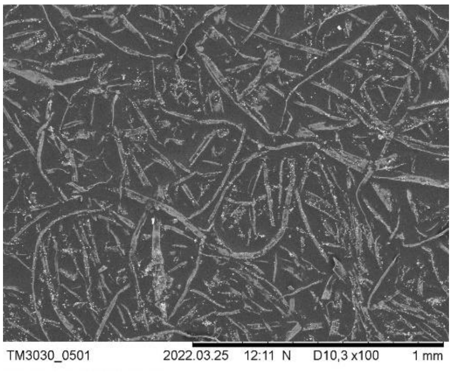

Fig. 2. **Algae fibres on the paper surface SEM image, magnification 100x**

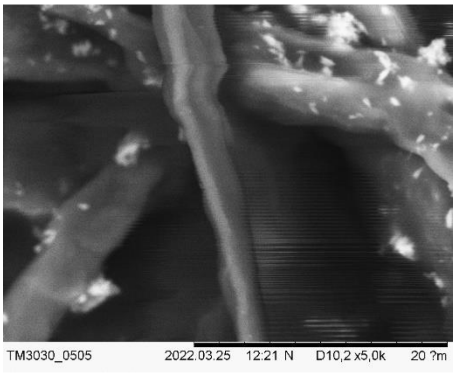

Fig. 3. **Close-up of algae fibre on the paper surface, SEM image, magnification 5000x**

The pulp also contains finer particles. In the SEM photograph in Figure 4, the cross-section of the fibre diagonally is about 20 μm, but for the finest fibres around/below 1 μm, which is already comparable to the wavelength of light in the optical range. Since the surrounding mass is filled with seaweed carrageenan, which on drying forms a homogeneous mass, bending of light rays follows more complex principles, subjecting to the gradient of the refractive index formed in the composition of fibres and filler.

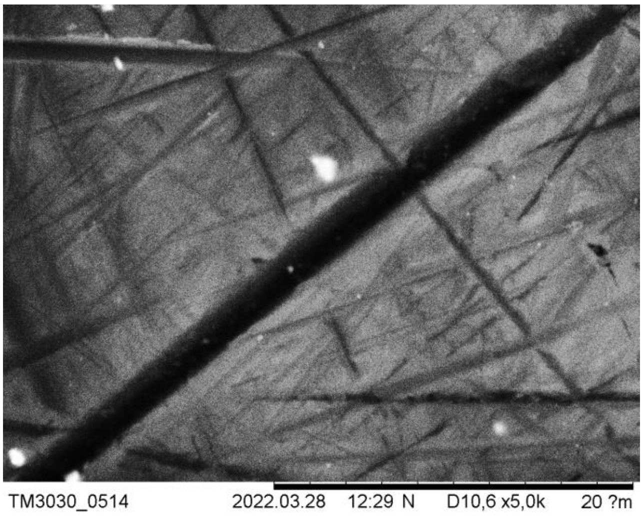

Fig. 4. **Algae fibres, SEM image, contrast edited, magnification 5000x**

This results in a visually observable scene where Figures 5 and 6 compare samples of the same paper in optical microscope images where large areas of red light do not form a shadow (Figure 4) and the finest fibres are not visible, while blue light shows them.

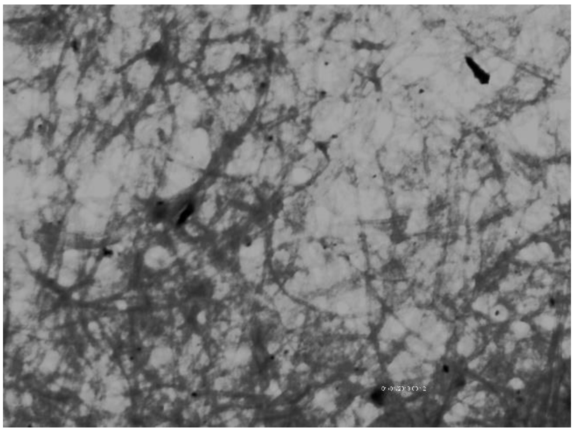

Fig. 5. **Algae fibres, OM image by 720 nm, unedited, grayscale**

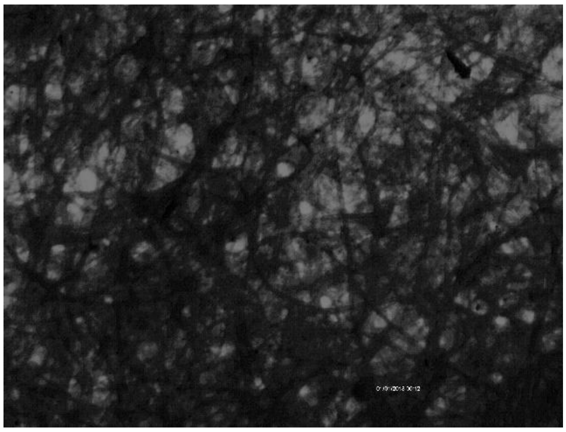

Fig. 6. **Algae fibres, OM image by 420 nm, unedited, grayscale**

For clarity, high-contrast images (Figures 7 and 8) of the same areas are presented, with two effects: 1) larger areas where shadows do not form because they are formed by finer fibres, 2) coarser fibres form larger dark areas where light rays do not pass due to reduced resolution small gaps between the fibres. In general, the device makes it possible to assess the quality of the resulting sheet of paper visually or microscopically by assessing the ratio and arrangement of light and dark areas, and the size of the fibres can be judged by the differences observed in the blue- and red-light ranges.

This was not possible in previously developed quality control devices for fibrous materials such as paper, which used white light [20].

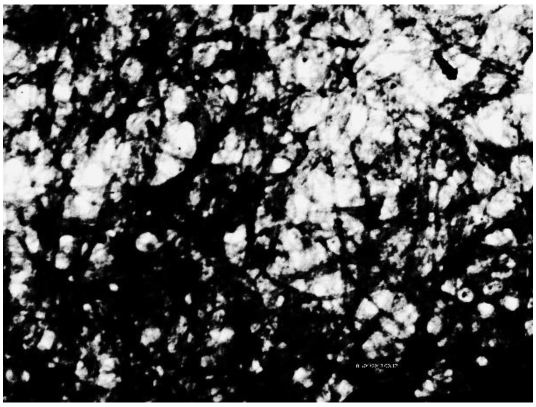

Fig. 7. **Algae fibres, OM image by 720 nm, contrast edited, grayscale**

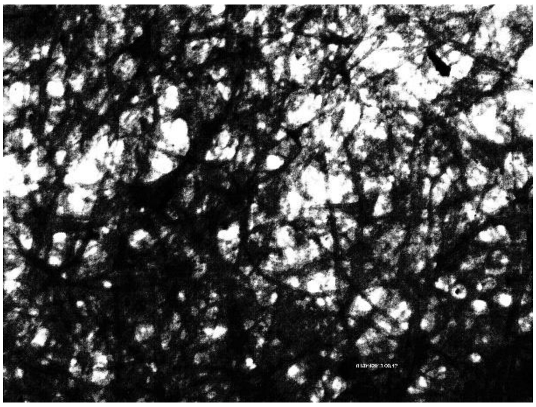

Fig. 8. **Algae fibres, OM image by 420 nm, contrast edited, grayscale**

Conclusions

1. One means of controlling the quality of the paper sheet produced may be a variable wavelength scanning device. The developed device is a novelty, similar fiber material control solutions have not been found yet.
2. The use of different wavelengths of visible light significantly increases the ability to evaluate the smoothness and layout of the paper pulp. It is possible to estimate the content of fibers with one of the dimensions (diameter) 400-500 nm and larger, considering the complex nature of the movement of light rays.
3. The quality assessment method provided is fast and non-destructive.

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Author contributions

Conceptualization and methodology, S.O. and U.Z.; software, A. K..; investigation, S.O. and U.Z.; writing – original draft preparation, writing – review and editing, S.O. and U.Z.; visualization, U.Z. and A.K.; project administration and funding acquisition, U.Z. All authors have read and agreed to the published version of the manuscript.

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