Professional paper
Received:20.6.2019
Accepted:3.12.2019
UDK: 630*8

BIO-BASED ECONOMY CASE STUDIES AT UNIVERSITY OF SOPRON

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ABSTRACT

Forest-based sector plays a significant and inseparable role through transition and implementation of 'bioeconomy', 'bio-based economy', 'circular economy' concepts and strategies. This paper aims to report few bio-based economy case studies conducted at the University of Sorpon, and is divided in three parts. The first part describes the investigation efforts on utilization of bark residues as a raw material for manufacturing of thermal insulation panels. The second part is focused on delignification of agricultural residues through an alkaline-hydrodynamic cavitation, and it examines their exploitation in paper and bioenergy production. Finally, the third part presents studies related to fabrication of nanocellulose films and composites for various purposes.

Key words: resource efficiency, bio-based insulation, hydrodynamic cavitation, nanocellulose

1. INTRODUCTION

Forests and other wooded lands cover over 40% of the EU's land area, with a great biodiversity. Forest-based industries in Europe provide the society with a wide variety of products and services which include: (i) wood working industries, (ii) pulp and paper industries and (iii) multi-product integrated bio-refineries. The most significant sub-sector is the woodworking sector [sawmilling, planning and wood impregnation (12%), furniture (41%)] and other woodworking industries (47%) which had a turnover of €129 billion in 2015, employed more than one million people in around 170,000 small and medium-sized companies. Additionally, 120,000 companies were active in furniture domain. The second largest sub-sector i.e. the pulp and paper industry comprised around 700 enterprises with an estimated turnover of € 81 billion in 2016, by employing about 175,000 people (Forest-based Sector Technology Platform, 2019).

Bioeconomy covers all sectors and systems that rely on biological resources (animals, plants, micro-organisms and derived biomass, including organic waste), their functions and principles (EC, 2018a). Several EU policies and initiatives have an impact on bio-based economy. The EU Bioeconomy strategy (Figure 1) and as part of it, forest-based roadmap directions targeted in a bio-based society, is built on various pillars, covering numerous approaches and areas such as: sustainable forest management and forest protection; ensuring food security; social, economic and environmental considerations; mitigating and adapting to climate change; investments in research, innovation and skills; education and training; reinforced policy interaction and stakeholder engagement; enhancement of markets and strengthening European competitiveness; rural development, creation of jobs and economic growth; resource efficiency and reduced dependence on non-renewable resources;

sustainable production and consumption of forest products; testing, standardization and certification (EC, 2013; EC, 2018a; Pelli, Haapala, Pykäläinen, 2017).

Figure 1. *Bioeconomy strategy graph (EC, 2018a) and biobased UN sustainable development goals (Biobased Industries Consortium, 2018)*

During the past few decades, the concepts of sustainability, bioeconomy, biobased economy, circular economy, green economy have appeared as frameworks for the visions and strategic orientations of the forest-bases industries (Hurmekoski et al., 2019; Pelli, Haapala, Pykäläinen, 2017). For instance, Näyhä (2019) in his study performed by interviews and surveys with Finnish forest-based companies, they concluded that bioeconomy was usually thought as a response to climate challenge by bio-based, renewable material, while circular economy was characterized by ideas such as resource efficiency, closed loops, recycling. Additionally, neither of them could be considered as inherent, sustainable, or green economy approached concepts. Likewise, according to Näyhä, many other studies connect the three Rs of ‘Reduction, Reuse and Recycle’ to circular economy. Moreover, Bugge, Hansen and Klitkou (2016) identified three visions for a bioeconomy: biotechnology, bio-resource and bio-ecology. Staffas, Gustavsson, McCormick, 2013 report that the term BE is most often used by those who define the concept as biotechnology, life science and related technologies and applications, whereas the term BBE is based on the use of biomass resources rather than fossil-based products and systems.

In line with the studies mentioned above, it can be deduced that the principles such as sustainability, bioeconomy and circularity should be deep down at the heart of a successful European bioeconomy. Even though it seems that i) that these concepts are used interchangeably and diversely comprehended by different actors’ and stakeholders’ sight and ii) these are overlapped and strongly interlinked to each other, still there are also descriptive differences among them. Furthermore, there are miscellaneous strategies in accordance with the natural policies and legislation, geographical characteristics, economic growth and development and market opportunities, but all of them are identified by common characteristics. Therefore, easily explicable is the existence of several and quite different explanations describing bioeconomy, bio-based economy and circular economy concepts (Figure 2). However, these concepts are well defined in other studies and it is not purpose of this work (D’Amato et al., 2017; Nattras et al., 2016; Staffas, Gustavsson, McCormick, 2013).

In a relatively recent report by the EU (EC, 2011), the following definitions regarding bio-based and bioeconomy concepts are given: ‘…a bio-based economy integrates the full range of natural and renewable biological resources, land and sea resources, biodiversity and biological materials (plant, animal and microbial), through processing and consumption of these bio-resources. Bioeconomy encompasses agriculture, forestry, fisheries, food and biotechnology sectors, as well as a wide range of industrial sectors, ranging from the production of energy and chemicals to building and transport…’. Mubareka et al. (2016) describe another similar definition related to bio-based economy as stated in one of EC publications, and define it as one using ‘…production paradigms that rely on biological processes and, as is the case with natural ecosystems, use natural inputs, expend minimum amounts of energy and do not produce waste, as all materials discarded by one process are inputs for another process and are reused in the ecosystem.'

The EU's wood-based industries cover a range of forestry downstream activities, including the traditional woodworking industries, furniture and building construction industries, pulp and paper manufacturing and cellulose-based applications and especially multi-product biomass innovative, value-added products such as biorefineries. A key factor in the transition to a bio-based economy is the growth of biorefinery systems. Biorefineries in a general perspective include as examples the production of bio-textiles, bio-chemicals, bio-lubricants, bio-surfactants, bio-pharmaceuticals, bio-adhesives, bio-plastics, 3D printing and flexible electronics etc. products, as well the bio-technology (enzymes etc.) and bioenergy (biofuels, biogas, heat and/or electricity) (Scarlat et al., 2015).

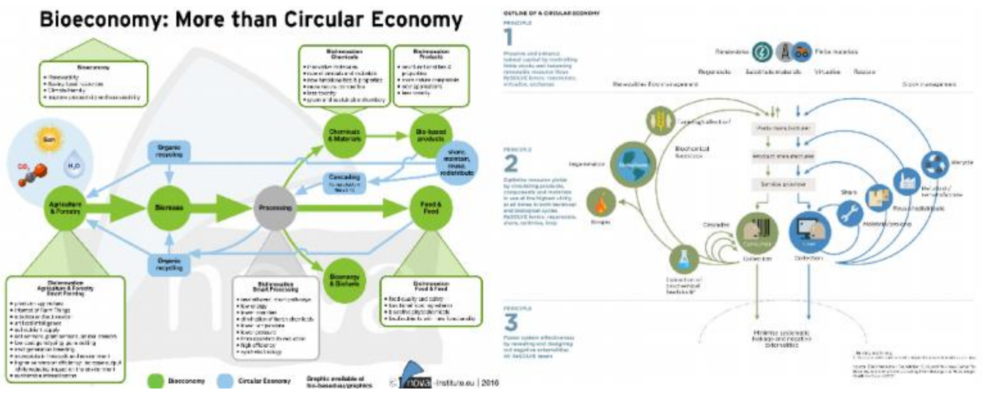

Figure 2. *Bioeconomy and circular economy concepts (nova-institute.eu; ellenmacarthurfoundation.org)*

The scope of this review is to present a brief summary of the near past and ongoing research and further to describe a few experimental case studies, implemented by the Innovation Center and Macromolecules Materials and Technology research groups, based on the Simonyi Károly Faculty of Engineering, Wood Sciences and Applied Arts at the University of Sopron.

2. BARK UTILIZATION AS INSULATION PANELS

Circular economy is an economic system in which 'valuable products, materials and resources are maintained in the economy for as long as possible, or by enabling circular economy actions plans by processing side-streams, residues and wastes into new value chain products. This can be achieved, for instance, by minimizing and/or recovering the generation of agricultural and forestry biomass waste and residues, and simultaneously maximizing their resource efficiency, recycling and reuse, i.e. 'circularity'. Key innovations in wood working sector, among others, include cascading use of wood industries residues (e.g. small diameter roundwood, sawdust and chips, thinnings, bark, tree tops and branches) as feedstocks in manufacture of wood pulps and biorefineries, wooden packaging, or wood based panels such as thermal, acoustic and vibration insulation boards (EC, 2018a; EC, 2018b).

Each year, a huge amount, millions of tons of bark remain as residual woody biomass in sawmills and wood-based industries. During 1960s, Martin investigated the bark thermal properties of three pines and seven hardwood specimens, and he showed that bark specimens indicated lower thermal conductivity values compared to similar density wood specimens. Lately, Kain et al. (2013, 2018) had been investigating utilization of usually low-density spruce and larch bark particleboards as thermal insulation panels. Likewise, Pásztory, Mohácsiné, Börcsök (2017) investigated the effect of black locust size particles (fine fraction: 1-8mm; medium fraction: 8-13 mm; and coarse fractions: 13-45 mm) on thermal conductivity values of 20 mm thickness and 300 kg m^{-3} density particleboards (Figure 3a). As shown by the results, the bark particles sizes had no significant effect on the mean thermal conductivity values (~ 0.065 W/m·K) of the black locust panels and was found to be in consistence with other relevant studies.

One of the main obstacles to fabrication of bark particleboards is the weak mechanical properties observed on the manufactured end products of wood-based panels or composites. A potential solution to overcome this issue could be their reinforcement with synthetic polymer fibres such as glass fibres. Therefore, the objective of a research conducted in our laboratory facilities was to examine the mechanical strength reinforcement of three commercial fibreglass types (GFRP) overlaid on both surfaces of bark-based boards, and their potential usage as insulation panels in building construction (Figure 3b).

Figure 3. *Black locust bark panels (a) and overlaid GFRP panels (b)*

The mean modulus of rupture (MOR) values of the control panels was calculated to be 0.54 MPa, while the mean MOR of fibreglass mesh 2.54 MPa, the mean MOR of fibreglass mat 2.82 MPa and the mean MOR of fibreglass woven fabric 4.45 MPa, which represent a percentage raise by 370%, 422% and 724%, respectively. The measured thermal conductivity mean values were ranging from 0.067 to 0.074 W/m·K.

3. HYDRODYNAMIC CAVITATION AS A DELIGNIFICATION METHOD

Alkaline assisted hydrodynamic cavitation has been testified to be an effective process for delignification and enhancement of enzymatic digestibility of grass agricultural residues biomass for converting it into biofuels such as bioethanol or biogas. Cavitation is the process of generation, growth and violent collapse of millions of vapor micro-bubbles within a few microseconds in the bulk of a liquid. This collapse is strong enough to generate high temperature and pressure conditions and induce chemical and physical transformations in the material. Cavitation can be produced by passage of ultrasonic waves through a liquid medium (acoustic cavitation) or by pressure variation in a flowing liquid, which can be caused by constriction through a channel such as venturi tube, orifice plate or rotor-stator assembly (Baxi and Pandit, 2012; Hilares et al., 2016; Patil et al., 2016).

Part of current research conducted in our groups deals with delignification of agro-waste such as wheat straw (Badve et al., 2014) or *Miscanthus x giganteus* stalks and other agricultural residues, through combination of an alkaline-hydrodynamic cavitation approach for production of papermaking pulps (Figure 4).

Figure 4. *Hydrodynamic cavitation device and agro-waste paper handsheets*

It was clearly shown by Badve et al. (2014) that as cavitation parameters, i.e. treatment time and rotation speed was increased, tensile index of the wheat origin paper handsheets was linearly increased. Furthermore, as the wheat to 0.3 M KOH aqueous suspension consistency ratio was increased from 5% to 7%, the tensile index grew by 50%. This effect can be attributed to enhancement of surface velocities generation, i.e. the growth of cavitation intensity and the formation of more reactive hydroxyl radicals (OH·) as the cavitation conditions (rotation speed and time) increased, which, in turn, resulted into rise in the overall delignification rate. Chemical composition analysis of hydrodynamic cavitation treated miscanthus pulps exhibited lower lignin and hemicellulose contents and raised percentage of α-cellulose, compared to raw (untreated) miscanthus, as cited by relevant literature (Rodrigues, Jackson, Montross, 2016; Vanderghem et al., 2012). More specifically, lignin content was found to be 15.90% (dry basis weight) and holocellulose content 77.28% - comprised of 60.75% α-cellulose and 15.90% hemicelluloses content - at 7% miscanthus to suspension consistency and 20 min cavitation time at a rotation speed of 2,500 rpm.

4. CELLULOSE BASED STUDIES

The significance and importance of cellulose and cellulose-derived materials is depicted by the numerous publications and ongoing research projects due to the environmental, chemical, physical, barrier and mechanical properties of these cellulose-derived materials. They can be used in heterogeneous shapes and forms as reinforcement fillers, films, aerogels, hydrogels, filaments, hybrid nanocomposites in various fields including biomedicine and cosmetics, electronic/smart material devices, food packaging industries, in pulp and paper industry and even automotive and aerospace industry (Nechyporchuk, Belgacem, Bras, 2016; Sabo et al. 2016).

Poly(lactic) acid (PLA) is a commonly used biodegradable, bioplastic which is used extensively in packaging industry. However, one of its bottlenecks is its unsuitability for storing liquid products due to its high water vapor and gas permeability. Halász, Hosakun and Csóka (2015) managed to reduce the water vapor transmission rate of PLA bottles and films, and to extend their shelf-life time by almost 1/3, through a chitosan (CH)-cellulose nanocrystals (CNCs) nanocoating applied by a self-assembly, electrostatic layer-by-layer (LbL) deposition method. The four-time bilayer impregnating CH-CNCs coating was found to be more efficient, compared to the eight-time CH-CNCs LbL technique, as is illustrated in Figure 5.

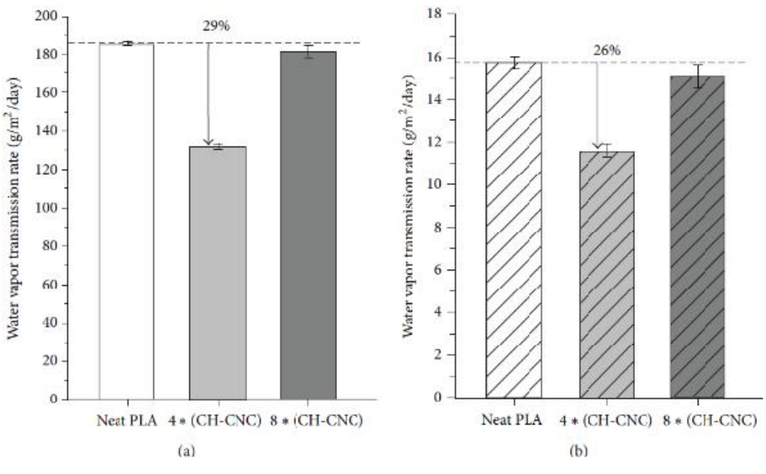

Figure 5. *Water vapor transmission rate of neat and CH-CNCs nanocoated poly(lactic) acid films (a) and bottles (b) through a LbL method*

Khatri et al. (2014) functionalized bleached pine pulp fibres with previously saccharide (glucose, sucrose, starch and alginic acid) modified ZnO nanoparticles and then tested the suitability of the produced handsheets on detection of blood types, besides their antibacterial and antifungal resistance (Figure 6). Bradford reagent was used as a medium to quantify the degree of blood antibodies immobilization with the ZnO modified cellulose sheets. Results have shown that the alginic acid ZnO impregnated handsheets in particular could successfully differentiate the retention degree of blood antibodies and identify the blood type at a percentage rate of about 95%.

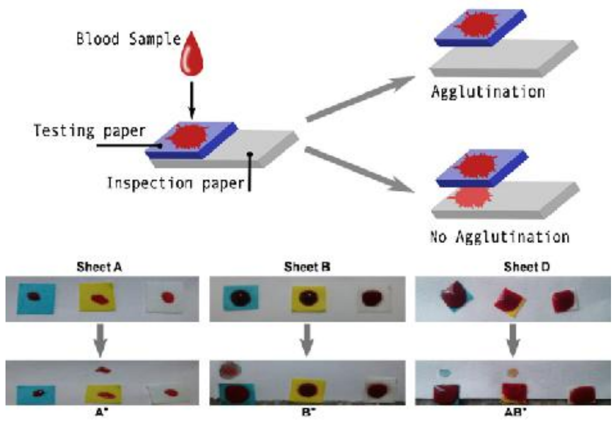

Figure 6. *Schematic illustration and images of blood type detection tests with alginic acid ZnO impregnated pulp handsheets*

In one of our previous studies, it was shown that sonication with an ultrasound horn is an efficient method of producing smooth, thin and relatively transparent BC films by a simple solvent casting method (Tsalagkas et al., 2016), which potentially could be used as substrates in smart applications such as piezoelectric energy harvesting or electric devices. Based on this study, Hosakun et al. (2018) assessed the potential of BC blend films incorporated with silk fibroin (SF), polyvinyl alcohol (PVA) and silver nanoparticles (Ag) as flexible organic light emitting diode (OLED) substrates (Figure 7). For this purpose, the co-authors examined the viscoelastic and electrical properties of the obtained films by performing complex conductivity and DMA analysis tests, under the influence of photoelectric effect (light) and above the glass transition temperature (T_g). According to their findings, the most favorable films were the BF-SF-PVA-Ag since both PVA and Ag displayed synergistic effect on the final performance of the investigated films.

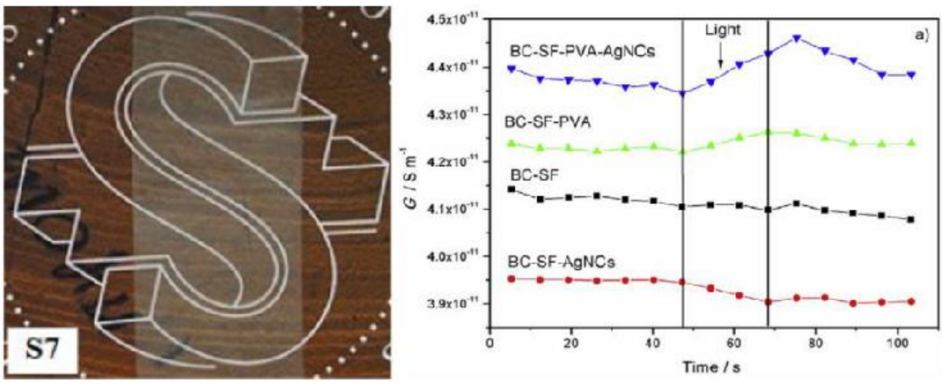

Figure 7. *BC-SF-PVA-Ag films (left) and specific conductance (G) measurement of the overall films at 22 kHz as a function of time performed on an Agilent 4284 A (right)*

5. CONCLUSIONS

This review has provided a short outline of the recently published and unpublished investigations carried out on bio-based focused research carried out by our groups. In this paper we attempted to summarize their methodology, main results and outcomes prompted by our studies.

Transition from a fossil-based industrialization and dramatic climate change to a sustainable, low carbon and environmental impact, resource efficient, profitable and competitive economy with innovative, value added, bio-based products is a major challenge and still demands a lot of research and emergence of new technologies. The European Commission, through its continuous research funding opportunities, and strategic orientation policies, has already set the foundations for accomplishment of a green, circular economy based Europe by 2050. For successful completion of these long-term targets, and in compliance with the recent results and developments accomplished through the Horizon 2020 projects, forest-based sector had an important share. It will continue to play a crucial role in the forthcoming framework programme Horizon Europe in line with the targets presented in the 'Vision 2040 of the European forest-based sector' and 'The forest fibre industry 2050 Roadmap to a low-carbon bio-economy' publications, as issued by the Forest-based Sector Technology Platform (FTP) and Confederation of European Paper Industries (CEPI) organizations, respectively.

Acknowledgements This work was supported by the 'Sustainable Raw Material Management Thematic Network – RING 2017', under grant EFOP-3.6.2-16-2017-00010 project in the framework of the Széchenyi 2020 Program. The realization of this project is supported by the European Union, co-financed by the European Social Fund.

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