48. ACTUAL TASKS ON AGRICULTURAL ENGINEERING

Review paper

ENERGY UTILISATION OF BIOFIBRE PRODUCTION RESIDUES – CIRCULAR ECONOMY APPROACH

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ABSTRACT

The circular economy treats waste as a new resource, and existing products are tried to be left in circulation for as long as possible or returned to the market in some other form after the reuse of production raw materials. In modern time the textile industry is an enormous polluter. More than two-thirds of waste goes to landfills which is a big problem due to the release of greenhouse gases and pollution of land and groundwater. Textile waste is divided into industrial and post-consumer waste. This paper is oriented to industrial waste of textile biocomposites production and its disposal by incineration, thinking about the application of the principles of circular economy and sustainable development. Biocomposites are materials made up of natural fibres (a component of biological origin) and a matrix (of biological or non-biological origin). In the textile industry, there is a growing trend of biocomposites production for the different industries due to its properties. The use of biocomposites in the industry comes to the fore because biocomposites are lightweight, solid and biodegradable. The application of biocomposites in industry creates a new type of waste consisting of various polymers and natural fibres. The option for disposing of this type of waste is incineration which leads to the sustainable energy production, based on the circular economy approach.

Keywords: *biocomposites, natural fibres, industry residues, sustainable development*

INTRODUCTION

The circular economy considers the impact of resource consumption and waste on the environment. This leads to the creation of alternative closed loops in which resources are in the circulation of production and consumption. The goals of the circular economy are to optimize resource use and reduce pollution as much as possible. The circular economy differs from the linear one in that the linear economy is based on the principle: extract, produce, consume and dispose without considering the impact on the environment, i.e., it is based exclusively on economic goals.

However, the use of raw materials in a circular economy is based on reducing their use and optimizing the use of by-products and waste to reduce resource utilization and the impact of production and consumption on environmental pollution (Pinjing et al. 2013). In principle, the main difference between a linear and a circular economy is adherence to the principles of sustainable development. The circular economy can be considered as a sustainable economic system in which economic growth is separated from the use of resources, by reducing and recirculating natural resources (Corona et al. 2019). As shown in figure 1 circular economy is based on using produced materials as much as possible and waste is generated only if there is no possibility of recycling.

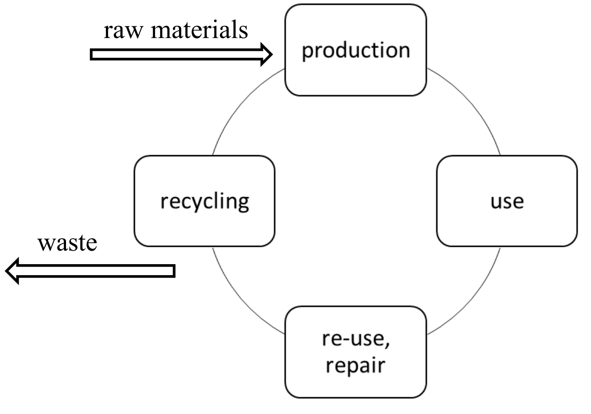

Figure 1 Principles of circular economy

Sustainable development can be defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." (World Commission on Environment and Development, 1987; Sauve et al. 2015). Applying the principles of circular economy, resources (production waste) are kept in circulation as much as possible, in order to maintain value or by conversion from waste to energy (Shirvanimoghaddam 2020). By reusing waste, the utilization of fossil fuels is reduced and thus a valuable resource is preserved, the impact of pollution is reduced because landfill waste is used for energy. Basically, some type of waste could be considered as a renewable source of energy that can be used to produce heat or electricity (Merrild et al. 2012; Sansaniwal et al. 2017; Nunes et al. 2018; Tursi 2019; Kpalo et al. 2020).

European Commissions has developed The European Green Deal which is an integral part of the Commission's strategy for implementing the United Nations Program and the Sustainable Development Goals. It is a new growth strategy that seeks to transform the EU into a justice and prosperous society with a modern, resource-efficient and competitive economy in which there will be no net greenhouse gas emissions in 2050 and in which economic growth is not linked to resource use. In addition, it pays attention to the protection, preservation and increase of the EU's natural capital and to the protection of the health and well-being of citizens from environmental risks and the impact of the environment on them. Achieving a climate-neutral and circular economy requires the full mobilization of industry. It takes 25 years, or one generation, for the industrial sector and all value chains to transform.

The Circular Economy Action Plan from New Green Deal will include a “sustainable products” policy to support the circular design of all products based on a common methodology and principles. Priority is to reduce and reuse materials before recycling. Although the Circular Economy Action Plan will serve for the transition of all sectors, action will focus in particular on resource-intensive sectors, such as the textile sector, construction and the electronics and plastics sector. It will also develop a regulatory framework for biodegradable and biological plastics and implement measures related to single-use plastics (New Green Deal, 2019).

In last few decades textile consumption has doubled from approximately 7 to 13 kg per person annually. More than two-thirds of this waste goes to landfill, and only 15% is recycled (Rada et al. 2018). Textile industry waste can be divided in two categories, first is industrial waste and the second is post-consumer waste (Echeverria et al. 2019). Industrial waste represents the waste generated during production process (for clothing, biocomposites or industrial purpose) and it represents significant source of secondary raw materials that are not used and can be put on market again. Post-consumer waste is fibre products that are discarded after their lifetime/use (Rada et al. 2018; Wang 2010). Waste management in European union is defined by Directive 2008/98/EC on waste in which is required that the waste be managed without endangering human health and harming the environment, especially water, air, soil, plants or animals and it is applicable in waste management hierarchy: prevention, preparing for re-use, recycling, recovery and disposal. Incineration in this case finds its application, it is a practical treatment that is widely used for the disposal of textile waste, for example a mixture of cotton and polyester has a good calorific value, i.e., HHV of 16MJ / kg (Ryu et al. 2007).

EXTRACTION METHODS FOR NATURAL FIBRES

All plant fibres are qualified separately from the part of the plant from which the fibres are extracted. Accordingly, the fibres are divided into bast / bark / stem fibres, leaf, fruit or seed fibres. The main goal of processing is to obtain the maximum amount of fibre of the highest possible quality (Zimniewska et al. 2013).

The process of obtaining fibres depends on the used method: physical mechanical, biological or chemical. Method that will be used for obtaining fibres depends on the type of plant. Therefore, some of the most commonly used procedures are: decortication, splitting using knife, various retting processes, alkali treatments, manual extraction and microwave treatment (Satyanarayana et al. 2009, Kovačević 2019). The oldest way of fibre extraction is manual extraction and it is considered as a physical method. Microwave treatment is also part of physical method for fibre extraction. This method was developed by group of scientists from Department of Textile Chemistry and Ecology, Faculty of Textile Technology in Zagreb. The method is based on low concentrated sodium hydroxide mixed with fibrous material and microwaved using Teflon reactor (Kovačević et al. 2015). Decortication as a part of mechanical method is a procedure that uses a decorticator machine to remove the bark. Splitting using knife also falls in the mechanical method and is famous for obtaining piassava and coir fibres. Retting which is microbial process for obtaining fibres, especially flax fibres, is considered as a biological method which relies on bacteria and moisture to break down plant parts around the fibres. There are several types of retting: dew, water and enzymatic retting. (Kumar and Sekaran 2014). The most used chemical methods are alkali and acid treatments which include alkaline extraction, bleaching and acid hydrolysis. During these methods most of the lignin and hemicellulose bonds are removed (Abraham et al. 2011; Zakikhani et al. 2014).

In recent years, there is a greater demand for the production of fibres to be used in the composite industry than for fibres to be used in the fashion technology. Production of fibres for composites (biocomposites) purposes sometimes requires usage of different extraction methods if aforementioned are not useful for a specific application. The kraft pulping process is a chemical method used for conversion of wood and non-wood plants to cellulose pulp often used as reinforcement in the composite materials. Cellulose pulp means relatively short and finer fibres compared to the fibres obtained by already described extraction methods, although pulp from non wood plants have longer and stronger fibres with lower lignin content compared to wood pulp. The kraft pulping process is carried out by mixing hot water, sodium sulfide (Na_2S) and sodium hydroxide ($NaOH$). This mixture divides cellulose from hemicellulose and lignin. In this type of extraction, one of the residues is black liquor that is interesting for energy utilisation of production residues (van Dam 2008).

BIOCOMPOSITE PRODUCTION – NATURAL FIBRES

Composites are materials consisting of two (or more) phases, a solid reinforcement phase and a matrix. These two separate components when combined, i.e. when the solid phase is incorporated into the matrix, form a new material. The advantage of such joining of materials is manifested in the fact that high strength and stiffness of the fibres can be used to transfer the load (Fowler et al. 2006).

Biocomposites are composite materials whose phases (one or more) are derived from biological origin. This includes natural fibres from different non wood plants, wood, paper, food and energy crops. These fibres are beneficial because of it is low cost, lightweight, strength and stiffness, so the properties of composites are measured by the properties of the fibres (Fowler et al. 2006; Muthuraj et al. 2017A). Energy crops fibres are especially beneficial because of low cost, high yield, low input and short vegetation time. For example, miscanthus fibres have strong reinforcing effect, switchgrass have similar tensile strength as other natural fibres, hemp and china reed have lower cost and lower density, nevertheless energy crops end of life incineration results in energy and carbon credits (Joshi et al. 2004; Sashoo et al. 2013; Muthuraj et al. 2017B). A study conducted on the life cycle assessment of transport pallets of polypropylene (PP) and china reed fibres compared to glass fibres shows that PP / china reed fibre pallets have an environmental advantage even though they have a shorter lifespan, 3 versus 5 years from glass fibre pallets (Corbière-Nicollier et al. 2001). It is possible to use silvergrass and china reed as a substitute for wood production of plywood because they consist of cellulose, hemicellulose, lignin and extractives so their physical-chemical characteristics are similar to those of wood (Liao et al. 2012). Especially the application of biocomposites is found in the automotive, construction, packaging and furniture industries. Currently, the main markets for biocomposites are the construction and automotive sectors. Biocomposites in comparison with glass fibre composites shows that the structure of natural fibres acts better to provide insulation from noise and the effects of temperature. The density of natural fibres is lower compared to glass, which reduces the weight of the produced biocomposite. Also, biocomposites are used due to resistance to mechanical, electronic and thermal insulation, resistance to fire and wear, and primarily due to environmental impact (possibility of decomposition and recycling) (Riedel & Nickel 1999; Bhattacharyya & Jayaraman 2003; Hautala et al. 2004; Fowler et al. 2006; Koronis et al. 2013; Muthuraj et al. 2017A; Nagalakshmaiah et al. 2019). Replacing glass fibres with natural fibres leads to the reduction in overall car fuel consumption due to their low density and higher volume fraction which results in lightweight materials. Parts of cars made from biocomposites are panels, shelves, pedals and various external covers. The application of biocomposites in this industry is interesting because the strength and properties of the materials meet the requirements such as biodegradability, renewability and non-toxicity to the environment (Nagalakshmaiah et al. 2019). The advantages of using natural fibres in the production of composites are numerous: plant fibres are a renewable raw material, their production has less impact on the environment than the production of glass fibres, CO2 emissions after lifetime is neutral compared to the amount collected during growth. The technical advantages of using natural fibres are strength, stiffness and low density. Natural fibres have higher fibre content for the same performance, high fibre volume reduces the volume of use of the base polymer matrix which reduces the weight of the newly formed component and reduces the amount of use of the polymer that is a pollutant (Bledzki & Gassan 1999; Joshi et al. 2004).

Natural fibres used in composites with biodegradable polymer are the best option as an environmentally friendly material. However, at the end of use natural fibres (as opposed to glass) can be incinerated. The energy value of natural fibres in china reed fibres is 14 MJ/kg, which means the energy efficiency of natural fibres at the end of their life cycle is possible (Bledzki & Gassan 1999; Joshi et al. 2004).

BIOCOMPOSITES WASTE PROPERTIES AS SOLID BIOFUEL

Biofuels are fuels obtained directly or indirectly from biomass and they can be divided into three categories: solid, liquid and gaseous. Solid biofuel valorisation is based on proximate and ultimate analyses. Proximate analysis is important for understanding the combustion of biomass, and consist of the percentage of moisture content, ash, volatile matter (VM) and fixed carbon (FC) (Saidur et al. 2011). Higher heating value or calorific value is energy available in feedstock i.e., represent energy content of biomass in dry basis (Saidur 2011; Tanger 2013; Hartmann 2017). Ultimate analysis is used to study the properties of biomass, the analysis determines the ratios and percentages of elements such as: nitrogen, sulphur, chlorine, carbon, hydrogen and oxygen.

Moisture content is a measure for biomass amount of water and is expressed as a percentage (%) of the mass on a wet basis. The high moisture content affects the energy of fresh biomass because the heat released during combustion is consumed by the evaporation of moisture, therefore the preferred moisture content in the biomass is 5 - 15% (Bridgwater et al., 2002; Tanger et al. 2013). Inorganic residue that is produced by combustion of biomass fuel is called the ash (McKendry 2002; Hartman 2012). Ash content is inert material, and it reduces heating value of the material because it does not contribute to the release of total heat (Avelar et al. 2016). It lowers the value because the melting point of dissolved ash can be low and therefore causes problems with ignition and combustion (Saidur et al. 2011). VM content is mass loss as gaseous product (not including moisture) by heating. High content of VM can improve ignition and burning process and in that way, it affects whole combustion process (McKendry 2002; Tanger et al. 2013; Avelar et al. 2016). FC content is mass that remains after releases of volatiles, not including ash and moisture content (McKendry 2002). High values of volatile matter and fixed carbon have positive impact of overall heating value of any biomass (Saidur et al. 2011).

The replacement of polymers in more sustainable materials of biological origin as biopolymers is a growing trend in various industries such as automotive (de Moura et al. 2017), packaging (Coles & Meredith 2014) and construction (Pacheco-Torgal 2016). The result of switching to biopolymers is the creation of a new waste stream, which could be composted (but not a good option to cover demand). An option that would cover the demand for waste disposal is incineration (Al-Salem et al. 2009; Moliner et al. 2018).

Molnier et al. (2018) studied energy valorisation of biocomposites where sisal fibres were used as natural fibres with virgin poly-lactic acid (PLA). Fibres were designated to biocomposites in two groups. First group was in ratios of 10%, 20% and 30% of fibres in biocomposites, and other group with same ratios but with addition of coupling agent. Proximate analysis (ash content, volatile matter and fixed carbon) and calorific value were made and compared between PLA and group 1 and group 2 (with coupling agent). Ash content between two groups varied between 1,9 to 6%, the lowest value was found at group 2 that had 10% sisal fibres with coupling agent and highest values were found at both groups that had mixture of 30% fibres with PLA, while PLA had only 0,6% of ash content. The volatile matter did not deviate from each other with values ranging between 91,2 to 95,6%, while the control group had 98,2% of volatile matter. Values of fixed carbon differed a bit, the lowest value of 1,4% is at group 1 in 10% fibres mixture, and the highest value is 2,8% in group 2 30% with coupling agent, while PLA value was 1,2%. For all samples a calorific value was made, HHV did not deviate much from each other the lowest value was 15,06 MJ/kg and the highest 15,77 MJ/kg while PLA value was 15,73 MJ/kg.

In the research by Kovačević et al. (2019), stem residues from *Spartium junceum* L. (SJL) fibre production were studied for obtaining the second generation of biofuels. SJL fibres were obtained by two methods, the first is the saltwater extraction method and the second extraction method is by microwave maceration. Proximate and ultimate properties of biomass and calorific value were determined for the analysis of production residues. Moisture content in biomass is recommended to be kept below 10 to 15%, and in samples obtained by saltwater extraction moisture content is 7.46%, and in the sample obtained by microwave maceration is 6.53%. Ash content between the two samples does not have a significant difference ranging from 4.37 to 4.77%, which is in the expected range because *Spartium junceum* L. belongs to agricultural biomass, which otherwise has a higher percentage of ash due to chemical composition and mineral content. The values of fixed carbon in saltwater extraction are 10.47%, and the value of the sample obtained by microwave maceration is 13.22%. Calorific values were obtained using the Higher heating value HHV which is 17.23 MJ/kg for the sample extracted with salt water and 18.6 MJ/kg for the sample obtained by microwave maceration. This indicates a satisfactory biomass that can be used to obtain solid biofuel.

Considering that nowadays we are facing with frequent use of cellulose pulp as a reinforcement in biocomposite materials, it is important to pay attention at the waste liquid that remains after kraft pulping process in which lignin is separated from cellulose fibres in a digester system with NaOH and Na_2S. This waste liquid that remains after rinsing (removing the cellulose pulp), is called black liquor.Black liquor is a mixture of organic and inorganic materials with high amount of total dissolved solids. Its chemical composition depends on the type of raw material used for kraft pulping (the process is applied to the production of wood pulp and non-wood pulp such as: bagasse, straw, grass and bamboo) (Huang et al. 2007; Cardos et al. 2009). Black liquor is a complex aqueous solution containing organic substances of plant origin (lignin, polysaccharides and resinous compounds) and inorganic compounds (soluble salt ions). Since black liquor calorific value varies from 14 to 16 MJ/kg HHV it can be used as industrial fuel which is especially the case in a paper producing countries. Incineration of black liquor is combined with the combustion of bark and other wood fuels but first the excess water needs to be removed by drying techniques (Demirbas 2002; Cardos et al. 2009). In most kraft mills black liquor is evaporated from 15 – 18 % to 55 -85% solids content so it can be burned in the recovery boiler to maximize the heat recovery (Bonhivers, J-C. et al., 2013; Bajpai, P., 2018)

CONCLUSION

Disposal of textile industry residues currently is not environmentally friendly, and it does not follow principles of circular economy and sustainable development. By applying these principles, it is possible to create more sustainable disposal solutions. Biocomposites as new eco-friendly materials create a new type of waste that is biodegradable and can be used for energy production via incineration process. Relying on the results obtained by the research of proximate analysis and calorific values of the investigated material, it can be concluded that residues after fibre production can be used for solid biofuel production. Such a way of exploiting raw materials to produce biocomposites and then exploiting the remains of raw materials to produce solid fuels corresponds to the definition and practice of circular economy and sustainable development. The possibility of use energy crops biomass in the production of biocomposites of lower weight, improved strength and resistance to burning makes these cultures interesting for further research and application, especially because of their ability to recycle and utilize production residues.

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