DESIGN AND MANUFACTURING OF SUSTAINABLE INDUSTRIAL PACKAGING FROM ALTERNATIVE LIGNOCELLULOSIC BIOMASS

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Due to high demand and increasing prices of wood-based cellulose, alternative sources of lignocellulosic biomass are gaining on their importance. Among them are invasive alien plants (IAP) that currently are being discarded (burned or composted) in spite the fact that they can be converted to useful products. For packaging of large home appliances, currently expanded polystyrene (EPS) is used. By exchanging EPS with cellulose-based (from IAP biomass) packaging, the circular nature of the packaging will be improved. Within the first stage of the LEAP project the potential of IAP biomass for conversion to cellulose and its use for production of foam formed packaging materials is being studied – various IAP have been evaluated in terms of their potential use for cellulose production, cellulose quality and key mechanical parameters. The data gathered is being used in computer assisted design and construction of packaging for large home appliances. A preliminary LCA analysis on the use of alternative raw materials as a source for cellulose production has also been performed.

Keywords:
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biomass,
alternative raw materials,
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1 Introduction

For the industrial packaging of heavier products such as big home appliances, most often the protective elements, made of expanded polystyrene (EPS), are being used. The main role of this protective packaging is to provide mechanical protection of the packed product including shock absorption during transport and handling. Having good shock absorption properties and being a lightweight material EPS has proven itself as a good solution for this purpose. However, in terms of material itself there are some drawbacks using EPS based packaging – its non-biobased origin, its poor recyclability and non-biodegradability. According to EUMEPS the recycling rate of EPS in Europe is around 32 %, making EPS packaging a challenge in terms of circular economy, so solutions for its exchange with more sustainable materials are being developed.

One of possible solutions is the use of cellulose fibre based packaging for production of foam formed protective elements. Compared with EPS based packaging the protective properties of cellulose based packaging are not as good as those of EPS packaging, so additional research of material properties and packaging design is needed.

In terms of material sources for cellulose production invasive alien plants (IAP) represent a good alternative to wood. While there is generally a shortage of wood-based cellulose on the global scale, raw material from IAP is widely available as according to EU Regulation 1143/2014 it must be removed from the environment in order to protect the biodiversity. Currently this biomass after cutting is being discarded by burning or composting, hence losing significant quantities of valuable cellulosic fibre material. By converting IAP into cellulosic fibre material new alternative source of cellulose from currently unused biomass will be gained, opening additional possibilities for its use in fibre-based packaging.

Within the LEAP research project various types of IAP are being studied in terms of their potential use for cellulose production, cellulose quality and key mechanical parameters for production of foam formed packaging. By exchanging EPS-based packaging with cellulose-based packaging from IAP biomass, the circular nature of the packaging will be improved while using the raw material from alternative, not wood-based source.

2 Materials and methods

2.1 Data on collection process for IAP

The data on existing processes for collection of IAP was gathered via questionnaire sent to the providers of public services. The questionnaire contained questions on frequency of IAP collection, type of collection process and treatment of IAP biomass after collection. Data was statistically evaluated and a general process scheme of collection process was designed. Furthermore a proposal for an improved collection process was made and comparison in terms of environmental impact was performed using the SIMAPRO software tool.

2.2 Evaluation of IAP potential for cellulose production

For the evaluation of IAP potential for cellulose production the IAP biomass was subjected to the kraft pulping process where after solubilizing extractives, lignin and hemicellulose, cellulose fibre materials were isolated by filtration, according to the procedure described in work by Kapun *et. al.* The chemical structure, mechanical, optical and morphological properties of were determined and compared to those of bleached eucalyptus pulp and unbleached softwood pulp. For the first series of evaluations, biomass originating from the stems of Japanese knotweed (*Fallopia japonica*) was selected.

2.3 Preparation of samples / prototypes

Cellulose pulp obtained by the kraft pulping process was used for preparation of standard test specimens that will be used for the performing the compression test of cellulose based protective packaging. The specimens were prepared by wet moulding process using pulp dispersion with 1 % solids content, where the solids composition was: 26 % commercial softwood pulp, 26 % commercial hardwood pulp, 35 % IAP pulp, 9 % inorganic fillers, 3 % cationic starch and 1 % sizing agent. The same pulp with addition of foaming agent was used for preparation of foam formed prototypes.

3 Results and discussion

3.1 Collection systems for IAP

Based on the results of the questionnaire it has been established that 72 % of public service providers have an established system for collection and removal of IAP. For removal process to be effective also the correct seasonal timing is crucial – only 44 % of public service providers collect and remove the IAP regularly (more than three times a year), while about one third performs the removal once a year and 22 % on request only.

After the IAP are removed from the environment proper handling of this biomass is extremely important. By using proper handling methods (such as incineration in incineration facility or burning on collecting site) potential spreading of IAP is prevented, while using improper handling (e.g. landfilling or composting) can potentially facilitate the spreading (Invasive Species Council of BC, 2021). In terms of handling methods one third of public service providers incinerate the collected IAP biomass, while one third handover the IAP biomass to landfill and 26 % use composting as IAP biomass treatment.

For potential industrial use of IAP biomass also the purity (in terms of material type) of collected biomass is important. It is desired that IAP are collected separately from other (native) plants and in case of areas where IAP are already the predominant species a separation by IAP species would be preferrable. Currently slightly more than a half of public service providers is removing and collecting IAP separately from native plants. However separate collection of individual IAP species is not performed by any of them as there is not enough data (including cost benefit analysis) on utilisation of IAP biomass for production of useful products such as pulp and paper or fibre-based packaging.

Within the evaluation of collection systems also a new system for collection of IAP has been proposed. Compared to existing collecting systems, where all streams are being collected centrally in one facility and then discarded by incineration or composting, in the new system the separation of IAP is done already on site during harvesting, followed by individual treatment of IAP material streams consisting of separation of wooden parts (stalks) from other residues (roots, leaves) and grinding the wooden parts into wood chips which are being used as raw material for production of cellulose pulp.

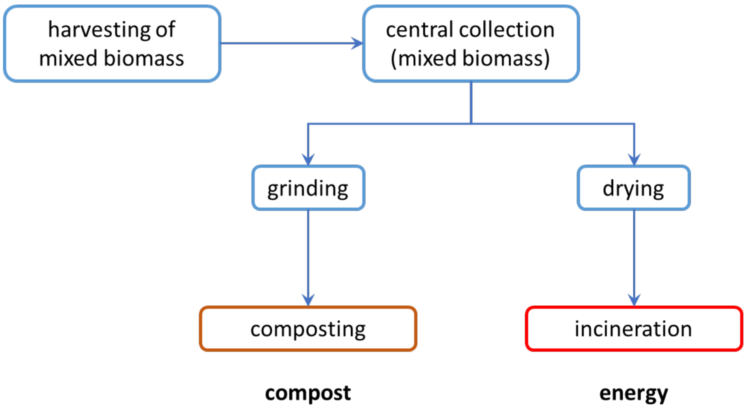

Figure 1: Process scheme of existing IAP collecting system
Source: own.

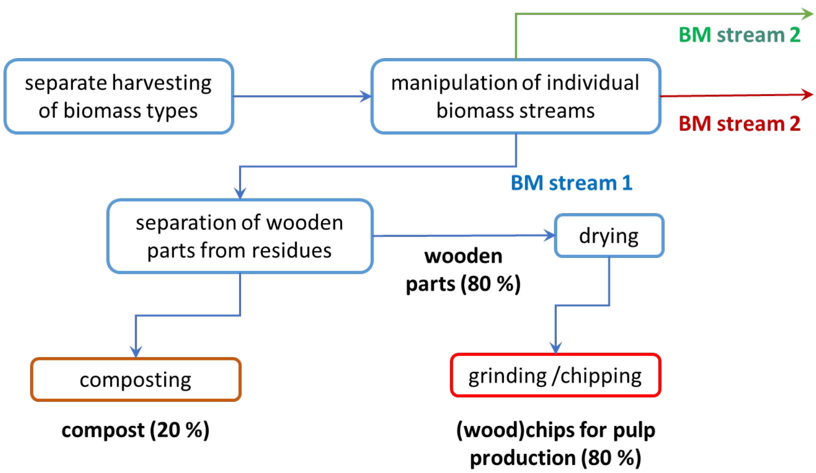

Figure 2: Process scheme of proposed new IAP collecting system
Source: own.

For both processes presented in figures 1 and 2 an LCA evaluation has been made by the SIMAPRO software using the ReCipe calculation method. The results show relative improvement (reduction) of environmental impact when using the new (modified) collecting system for IAP. Main improvements of environmental impact are seen in terms of reduced CO_2 and SO_2 emissions, reduced use of fossil energy, reduced water eutrophication and improved biodiversity. However it should be noted that, compared to the original process, the new process is giving intermediate products intended for further use and does not generate energy.

3.2 Potential of IAP for cellulose production

By using the kraft pulping process for treatment of wood chips from Japanese knotweed a fractionation of the IAP biomass into five main components (cellulose, hemicellulose, lignin, wood extractives and ash) has been performed. This was followed by determination of fibre morphology and main mechanical properties of obtained pulp. The results and a comparison to bleached eucalyptus pulp and unbleached softwood pulp are presented in tables 1 and 2.

Table 1: Composition of biomass from Japanese knotweed in comparison to eucalyptus and softwood

	Japanese knotweed	Eucalyptus	Softwood
cellulose (%)	35	54	57
hemicelluloses (%)	37	21	25
lignin (%)	27	26	26
extractives (%)	1,5	5	5
ash (%)	2,5	0,9	0,9

Table 2: Fibre and pulp properties of pulp from Japanese knotweed in comparison to bleached eucalyptus pulp and unbleached softwood pulp

	Japanese knotweed	Eucalyptus (bleached)	Softwood (unbleached)
fibre length (mm)	0,670	0,876	2,07
fibre diameter (μm)	19,7	14,88	27,74
cell wall thickness (μm)	6,86	3,77	4,95
fines (%)	6,58	4,41	4,13
fibrillation (%)	1,58	1,33	1,04
drainability (°SR)	17,5	14,5	12,5
tensile index (Nm/g)	33,91	19,24	20,51
tear index (mNm^2/g)	4,05	1,8	7,55
burst index ($kPam^2/g$)	1,68	0,67	1,04
stiffness (mN)	70,6	80,3	70,9

In terms of material composition Japanese knotweed contains similar portion of lignin as eucalyptus or softwood. The cellulose content is 35 %, however the difference (compared to eucalyptus or softwood) is compensated by significantly higher hemicelluloses content. Along with lower extractives content the ash content is more than double compared to eucalyptus or softwood.

In terms of fibre and pulp properties cellulose from Japanese knotweed can be positioned between the eucalyptus and softwood cellulose. Fibre length, diameter and fibrillation are more similar to those of eucalyptus, while the mechanical properties of pulp are more like those of softwood pulp.

In spite lower cellulose yield after pulping, it is viable to use Japanese knotweed for pulp production, considering the properties of pulp that are comparable to those of standard pulp used for paper production.

3.2 Samples and protypes

For the second stage of the research various samples for compression testing of cellulose based packaging products have been produced by the wet moulding process. The results of compression tests will be used for material modelling and design of protective packaging. Additionally, the production process for foam forming has been tested with samples of foam formed packaging material being produced. These samples will also be tested for their performance as potential packaging material for protective packaging.

Figure 3: Samples of wet moulded and foam formed packaging materials

Source: own.

Acknowledgments

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