LIFE CYCLE ASSESSMENT OF NEW BIO-HARDBOARDS USING A LACCASE ACTIVATED SYSTEM

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ABSTRACT

The use of petroleum-based resins in wood panels manufacture involves negative environmental effects mainly related to formaldehyde emissions. The substitution of these resins by formaldehyde free adhesives is proposed in this study. The environmental profile of a bio-hardboard formulated with a wood-based phenolic material and a phenol-oxidizing enzyme has been evaluated following the Life Cycle Assessment methodology and compared with those from the conventional process where phenol-formaldehyde (PF) resin is used as base adhesive.

The results indicate that the bio-hardboards meet the specifications of hardboards produced with the conventional process. The substitution of the PF resin by the bio-resin improves the environmental profile with reductions in both greenhouse gases and photochemical oxidants emissions. Special attention must be paid on the energy requirements of laccase production, which entails acidifying and eutrophying emissions.

INTRODUCTION

Wood based panels are characterized by their variable physical and mechanical properties as well as their multiple uses. These materials are composite boards which are manufactured using large amounts of synthetic resins derived from non-renewable resources (such as petroleum), which are increasingly more expensive (Widsten and Kandelbauer, 2008; Moubarik et al., 2009). Examples of the most extended conventional adhesives are urea and phenol formaldehyde resins (UF and PF respectively). Moreover, the use of these petroleum based adhesives implies formaldehyde emissions during the production and end-use of the boards. These emissions are a concern for society due to their negative environmental and health effects (Imam et al., 1999; Widsten et al., 2009). Therefore, there is a growing concern on the development of alternative and formaldehyde free adhesives which are expected to be more environmental friendly (Moubarik et al., 2009). Efforts are being devoted to develop these bio-adhesives as a green strategy using phenolic substitutes (Imam et al., 1999). Examples of potential bio-adhesives are composed by lignin based materials such as lignosulfonates and black liquor as well as bark tannins (quebracho) or starch (corn) which can be partially combined with UF and PF resins (Moubarik et al., 2009). The activation of lignin for bonding can be performed by oxidation with phenol-oxidizing enzymes (laccase and peroxidases) produced by white-rot fungi (Widsten and Kandelbauer, 2008).

The objective of this study is to evaluate the environmental consequences of using a two-component bio-adhesive with a wood-based phenolic material (lignosulfonate) and a phenol-oxidizing enzyme (laccase) instead of using the conventional PF resin. The evaluation has been performed following the Life Cycle Assessment (LCA) methodology since it has been proved to be a valuable method for evaluating the environmental impacts of products and for decision-making processes.

MATERIALS AND METHODS

As mentioned before, the main goal of this study is to assess the environmental consequences derived from the production of bio-hardboards by means of a green strategy where PF resin is totally substituted by a laccase activated system. To do so, an Austrian wood based panels factory has been assessed and inventoried in detail from a cradle-to-gate perspective following the ISO standards (ISO 14040, 2006). The functional unit (FU) considered in this study has been defined as 1 m^3 of hardboard (7% moisture content) for indoor uses.

Hardboards are fibreboards of uniform density ($\geq$ 900 $kg \cdot m^{-3}$) consisting on lignocellulosic fibres of European beech and Norway spruce processed under heat and pressure. The studied production system uses a smooth-one-side type production process, which renders into good natural fiber to fiber interfelting and bonding with minimum added binder required and provides a moist surface of high plasticity giving the desired embossing sensitivity (González-García et al., 2009a; 2011a). The green production of the hardboards bonded with both PF resin (conventional panel) or lignosulfonate and laccase (bio-panel) is carried out in a wet process.

Inventory data for the foreground system are related to the hardboard production process and consisted of average annual data (inputs and outputs) obtained by on-site measurements in the factory. Detailed description of both production lines (conventional and green) can be found in González-García et al. (2009a) and González-García et al. (2011a). Concerning the background system, inventory data were taken from bibliographic sources such as the production of wood (González-García et al., 2009b), laccase (Nielsen et al., 2007), lignosulfonate (González-García et al., 2011b) and the production of chemicals (e.g. PF resin) and electricity (Austrian profile) (Ecoinvent, 2007).

RESULTS AND DISCUSSION

The environmental study was performed using the characterization factors reported by the Centre of Environmental Science of Leiden University - CML 2001 method v2.04 (Guinée et al. 2001). This study is focused on four impact categories: acidification potential (AP), eutrophication potential (EP), global warming potential (GWP) and photochemical oxidant formation potential (POFP). Software SimaPro 7.3.2 was used for the computational implementation of all the inventories (PRé Consultants, 2013).

According to the comparative results reported in Figure 1, it is possible to obtain environmental benefits if the PF resin is totally substituted by a laccase activated bio-adhesive. These environmental improvements are achieved in categories such as GWP and POFP with reductions of 1% and 54% respectively. On the contrary, worse results have been achieved in terms of AP and EP.

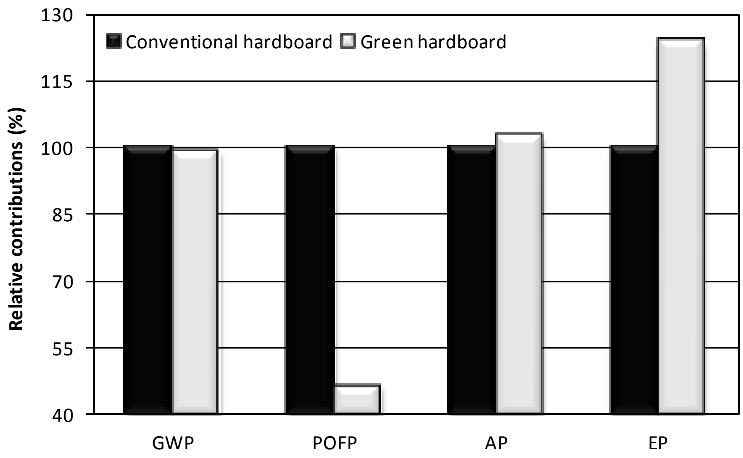

Figure 1. Comparative environmental profile of hardboards manufacture under conventional and green strategies.

Concerning energy requirements all over the life cycle, it is possible to obtain reductions of up to 30% for the green production system. However, special attention must be paid on the adhesives production. The conventional process requires 34 kg of PF resin as bonding agent per m^3 (González-García et al., 2009a) and the bio-hardboard requires 10.5 kg of laccase and 40 kg of lignosulfonate (González-García et al., 20011a), which is a co-product from dissolving pulp mills (González-García et al., 20011b).

The production of the PF resin is one of the most important processes responsible of environmental impacts derived from the conventional process specifically in terms of GWP and POFP as well as in toxicity related impact (which have not been assessed here). Thermal energy production process (from biomass) is the main responsible of acidifying and eutrophying emissions (AP and EP) due to nitrogen oxides emission (González-García et al., 2009a).

The bio-adhesive is composed by lignosulfonate and laccase. The contributions to the environmental profile from the lignosulfonate are almost negligible since it is a renewable material derived from wood and produced under a biorefinery concept (González-García et al., 20011b). The laccase production process is a high energy intensive process being remarkable its contribution to categories such as GWP and POFP (González-García et al., 20011a). However, in absolute values, its contribution is lower than the PF resin reducing the GWP and POFP.

Concerning AP and EP, thermal energy production is the main *hotspot* as in the conventional process. However, the contribution from laccase production process is considerably high involving higher absolute values.

CONCLUSIONS

LCA is a valuable tool for assessing the environmental profile of industrial systems and supports decision-making processes towards their sustainability. In this study, the LCA allowed to establish that environmental improvements can be achieved when petroleum based adhesives are substituted by bio-adhesives identifying the most critical contributor. However, more research must be carried out on the laccase production process in order to reduce its energy demand and thus, the environmental profile derived from the green hardboards. In addition, cost assessment should be required due to the large costs associated to laccase in comparison with formaldehyde based resins.

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