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A review of research on greening of packaging based on life cycle analysis

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Abstract. This paper examines and retrieves the whole process of packaging products from "cradle to grave" with the whole life cycle thinking, focusing on the stages that are more related to the packaging products themselves, including packaging design stage, packaging manufacturing stage, packaging use stage and packaging end of life stage, and carries out the methodological thinking of the development of green packaging. analysis. The process and technology of production and recycling of the most commonly used paper packaging materials are also discussed in order to promote the green and sustainable development of paper packaging.

Keywords: life cycle thinking; green packaging; paper packaginging.

1. Introduction

Carbon emissions are undoubtedly a constant part of our lives and have an impact on our environment. For example, based on the characteristics of products and current business models, disposable packaging for food and beverages such as milk tea and coffee, plastic lunch boxes, and multi-stage packaging for products under the prevalence of e-commerce. Although packaging was once glorious in the market to protect products, facilitate storage and transportation, and promote sales, and even caused the market preference and phenomenon of excessive packaging, it seems to form a negative public opinion image as people are concerned about environmental issues. The tracking and assessment of the carbon footprint of packaging and the search for effective carbon reduction methods are fundamental solutions for its sustainable development .

Carbon footprint analysis based on life cycle is a common method and has been applied in many fields, including raw material industry, building materials and construction, textile industry, electronics and automobile service industry, etc. In the field of packaging, carbon footprint analysis based on life cycle thinking can not only visualizes the carbon footprint of the production, transportation, use and recycling process of the product, but also compare the carbon footprint of different packaging to determine the focus of improvement. Luca Zampori and Giovanni Dotelli studied the sustainability of two types of packaging for poultry products, polystyrene-based trays and aluminum-based trays during their life cycle [1]. Bulim Choi of Yonsei University, Korea, measured the carbon footprint of three packaging films, LDPE, PLA, and PLA/PBAT blends, using life cycle assessment in conjunction with three different waste disposal scenarios. The analysis concluded that the PLA film scenario with landfill had the lowest carbon footprint and PLA/PBAT with incineration was the one that produced the highest carbon footprint [2].K.K. Weththasinghe compared the carbon footprint of wooden pallets made in Australia with plastic pallets made entirely from HDPE using LCA [3].Fabiana Bassani et al. proposed ecological design and the selection of transport means with low environmental impact by analyzing the life cycle processes of the three most common pharmaceutical packaging (blisters, sachets and bottles), including packaging production, assembly and distribution to pharmacies [4]. The utilization of life cycle assessment not only facilitates measures aimed at improving packaging design and production, but also collaborative efforts along the packaging supply chain. Therefore, the article adopts a process-based whole-life cycle thinking to track and analyze the carbon footprint of packaging, and elaborates on the greening of common paper packaging manufacturing processes and recycling. The

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content of the review reflects the importance of the carbon footprint contributed by the packaging industry and has some reference value.

2. Greening analysis of packaging based on the whole life cycle

The carbon impact of the whole life cycle of packaging can be divided into five stages: packaging design stage, packaging production stage, packaging transportation stage, packaging use stage and packaging end of life stage. The carbon impact of the packaging and transportation stage is mainly related to the logistics path, means of transportation, transportation energy consumption, information and intelligent technology of the logistics chain and other factors that are not very relevant to the packaging itself and therefore the greening analysis mainly focuses on the other four aspects.

2.1 The packaging design phase

The packaging design phase is not the process unit that generates the actual carbon footprint, but largely determined the environmental impact of the life cycle process. Peng Junwen et al. proposed that core design elements include direct design elements of product structure and process and indirect design elements of function and principle to achieve a grasp of multi-level carbon footprint to design or optimize product design[5]. Zicheng Zhu et al. focused on recycling or degradable considerations in terms of material use, manufacturing process and end-of-cycle environmental impact as well as a shift from the traditional one-way linear process of packaging life cycle to the closed-loop utilization of packaging resources[6]. The Australian Packaging Convention proposed ten principles for packaging design in June 2021, including (1) material aspects: optimization of material efficiency, elimination of toxic and hazardous materials, recycled materials and renewable materials (2) design aspects: design for resource recovery and recycling, design for waste reduction, design for commodity waste reduction and design for transportation efficiency (3) design accessibility and sustainable development information for consumers. In short, the underlying principle of sustainable packaging design is to produce as little or no environmental harm as possible while accomplishing everything standard packaging does, including product protection, transportation safety, and consumer consumption.

2.2 The packaging manufacturing phase

The greening of the packaging manufacturing stage is specifically reflected in the selection of environmentally friendly materials, simplification of packaging structure and improvement of production methods. In the selection of green packaging materials, the materials that meet the basic requirements of packaging are first selected from the candidate materials, then the greenness of the selected material is evaluated and the material with the highest greenness is selected [7]. With excellent heat and gas barrier properties and easy processing, biopolymer composites are a very promising green packaging material in terms of improving food quality and safety and reducing food loss and plastic waste. Biodegradable polymers such as chitosan, starch and PBAT are frequently used in food packaging [8]. In order to ensure the quality of packaging, green packaging is mostly composite packaging. In addition to saving resources, the reduction of materials can preserve more space for the lamination of multi-layer functional films, which can better adapt to the various requirements of products for packaging.

Process optimization is an important aspect of packaging greening. A research team from Sichuan University has successfully developed light weight and heat resistant PLA foam trays through supercritical carbon dioxide extrusion foaming and thermoforming process [9]. The Coca-Cola Company demonstrated the prospect of closed-loop use of plastics by converting recycled marine plastics into sample bottles through micro-polymerization technology [10].

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2.3 The packaging use phase

The main body of packaging use is the consumer. The greening of the packaging use stage can start from guiding consumers to use the packaging correctly and dispose of the packaging properly, focusing on the communication function of the packaging for the product and the description of the packaging, and guiding consumers to use, handle and store the product and packaging effectively and correctly [11]. The ecological design of packaging with additional functional design supports the secondary or even multiple use of packaging directly after use, such as Puma's innovative green packaging design "Clever Little Bag" for disposable shoe boxes, which can be used as a shoe storage box for travel and a flower pot for greenery. This design reduces resource waste and waste disposal [12]. In conclusion, the use of packaging should play a positive role in reducing the environmental impact of products, including improving packaging performance, reducing product waste, and ensuring product quality, while avoiding the negative impacts of packaging on products, such as the toxic effects of packaging chemicals on products and the migration of small molecules into products.

2.4 The end-of-life phase of packaging

End-of-life disposal scenarios for packaging include landfill scenarios, material recovery scenarios, energy recovery scenarios, and hybrid scenarios; for most packaging, material recovery scenarios are the most appropriate, landfill scenarios have the greatest impact on most products, and energy recovery scenarios are more appropriate for packaging with paper bags [13]. Recycling usually uses mechanical or chemical pathways used as raw material or energy recovery of valuable products, and the formation includes both closed-loop and open-loop recycling. For example, by controlling the physical and chemical properties of paper packaging, it can be used in the construction sector in a "new form of evolved wood". The paper material itself is a highly ecological material with sustainable characteristics, and the construction of buildings with paper can generate minimal waste [14].

To facilitate green recycling at the end of the packaging life, Marit Kvalvåg Pettersen et al. used a single recyclable HDPE material in combination with an aerated package to package fresh chicken fillet packaging, avoiding the use of multiple layers of materials and providing a solution for material use and increased recycling for different food system packaging [15]. Katharina M. A. Kaiser investigated the use of packaging adhesives modified with thermally unstable adducts for the preparation of multilayer packaging that facilitates separation and recycling [16].

3. Greening of paper packaging production and recycling

This section focuses on the basic process of paper packaging production in selecting raw materials, pulping and bleaching, the treatment of sludge wastewater after production and the recycling treatment of paper packaging.

3.1 Selection of pulp raw materials

Paper packaging raw materials include four main types of recycled paper, wood pulp, non-wood pulp, and non-fiber components, and paper packaging is usually composed of different shares of raw materials [17]. As the first step in the green production of packaging, the selection and composition of pulp raw materials can have an impact on the pulping method as well as on the quality and yield of the final production.Developing diverse sustainable pulp raw materials, exploring and improving the applicability of non-wood materials for pulp production, and reducing or even completely replacing the use of wood fibers is one of the important directions for sustainable paper packaging. Non-wood raw materials such as straw, rice straw, reeds and plant residues,can be used as alternative raw materials for pulp production and can enhance the paper strength of wood pulp paper [18,19]. For example, coconut husk can be used as a raw material for paper, fiberboard, and cardboard [20]. Alternative raw materials for wood pulp should be

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bioeconomical raw materials with low fertilizer requirements, high yields and meeting packaging standards.

3.2 Pulping and bleaching processes

The process of pulping includes four categories: mechanical pulping, chemical pulping, semi-chemical method, and biological method. Mechanical pulping promotes fiber separation by destroying the structure of wood chips, resulting in paper with low strength, high softness, and high brightness, which is usually applied to softwood pulping. Chemical pulping involves the use of chemicals under high temperature and pressure to remove hemicellulose and lignin, which increases the bond between fibers but reduces pulp yield. Semi-chemical pulping is a combination of mechanical and chemical pulping, with chemical treatment followed by mechanical treatment, and is suitable for corrugated boxboard. Biological pulping uses white-rot fungi to hydrolyze and degrade lignin, saving energy and improving paper strength[21].In pulping, ozone pretreatment is a simple, environmentally friendly, and cost-effective treatment. The combination of ozone treatment and thermochemical pulping methods can effectively degrade the surface lignin of paper fibers and improve fiber morphology, significantly improving paper strength [22].

Bleaching of pulp is usually carried out using biological enzymes, mostly xylanase, hemicellulase and lignin degrading enzymes acting in concert. Not only can they bleach effectively, but they also reduce chemical consumption and improve the brightness and tear index of the pulp. Usually the pulp making process is different and the subsequent bleaching method is also different.

3.3 Treatment of sludge wastewater after paper packaging production

After paper packaging production a large amount of cellulose-rich sludge material is produced, the main component of which is mostly short pulp fibers lost during the papermaking process. The technical treatment of sludge materials to produce valuable products is in line with the principle of sustainable development. It has been shown that enzymatic digestion is the best disposal method for sludge with relatively low lignin and ash content, and that hydrogen peroxide pretreatment and hydrogen chloride scrubbing for ash removal prior to enzymatic digestion can increase the accessibility and efficiency of the enzymatic action. Sludge is converted to glucose-rich hydrolysate by green chemistry, which in turn can be used to produce hydrogen, renewable fuels, and other chemicals through biotransformation techniques such as saccharification and fermentation [23], in order to achieve a valuable pathway for sludge utilization. However, the process of ash removal for the conversion of sludge often generates wastewater, which contains mainly organic matter and suspended solids. In order to reduce energy consumption and wastewater generation, the development of recycling technologies for wastewater, washing technologies with less water consumption or new technologies for ash removal are possible paths to be developed [24]. The main treatment processes for wastewater are initial screening and clarification followed by secondary treatment with oxidation, adsorption, membrane filtration, and chemical processes [25].

3.4 Recycling of paper packaging materials

The disposal of paper packaging waste includes landfill, incineration, and recycling. Landfills make the toxic substances of the packaging leach into the soil to produce toxicity, and incineration leads to the production of many toxic components; therefore, recycling is considered to be a more environmentally friendly option[26]. The recycling of paper fibers reduces the use of raw materials and also has the advantages of cost reduction, energy saving and waste reduction. However, recycled paper packaging materials themselves carry processing and functional additives that can migrate into food products and pose a risk to human health. Therefore, recycling technology for paper packaging requires two stages: high-density screening to remove dense objects outside the recycled paper and de-inking to reduce hazards and increase availability. The main objective of deinking is to remove specific dyes and obtain sufficient whiteness. The efficiency of deinking depends on a number of factors, including the nature of the substrate, the printing process, the type

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of printing ink, and the deinking process. Chemical deinking and enzymatic deinking are two commonly used deinking techniques, with cellulase removing ink particles from fibers by dissolving the ink and cellulose bonds, enabling more efficient use of recycled paper materials [27].

4. Summary and Outlook

The greening of packaging is a future trend and a strategy that requires long-term development. Whole life cycle analysis is a commonly used comprehensive, multi-level analysis method. The life cycle stages of packaging are an iterative process of mutual influence and interconnection, and thinking about greening in separate links is far from enough. Only through collaborative implementation of greening programs throughout the life cycle of packaging, including conducting design, material selection, production, use and effective recycling and reuse, can we approach the absolute green development of packaging and achieve environmental and cost benefits. Paper packaging is one of the most common types of packaging in life, although paper packaging materials come with environmental attributes, paper production, recycling and its disposal aspects are environmental problems. Therefore, the article describes the important processes of pulp raw material selection, pulping and bleaching, sludge wastewater treatment after paper packaging production, and recycling from the paper packaging production process as a way to promote the sustainable development of paper packaging.

At present, although the green transformation and upgrading of packaging is inevitably limited by ecological costs and technology in the early stage. However, with the progress of technology and process development and the increase of scale, the decoupling of economic growth and carbon emissions will be gradually realized. Meanwhile, the comprehensive application of big data, cloud computing and other technologies in packaging logistics has realized the sharing, transmission and storage of information, thus making the whole industrial chain more closely connected and more efficient as a whole, thus significantly reducing material consumption and energy consumption.

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