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The Challenges in Achieving a Circular Economy within Leather Recycling

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Abstract

Over the past two decades there has been a rapid growth in tanning and leather manufacturing in developing countries, an undesirable by-product of this is an increase in waste associated with leather products. End-of-life management options for leather products are often limited to incineration or landfill; these carry a range of environmentally damaging impacts. This indicates a need for an urgent diversion towards material recycling in order to prevent further environmental degradation. This paper investigates a number of interdependent and complex challenges in implementation of a circular economy approach within leather industry. These challenges range from achieving economy of scale required for commercial viability and finding secondary markets for the recycled materials to developing 'resource efficient recycling processes' that are especially tailored to the specific needs of leather products.

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Keywords: Reconfigurable Recycling; Circular Economy; Leather Recycling

1. Introduction

Leather is one of the most widely traded commodities in the world. Leather products industry plays a prominent role in the world's economy, with an estimated global trade value of approximately US$100 billion per year. [1]

Global population grew substantially in the 20th century and this combined with a general rise in wealth has led to a significant increase in the demand for meat, which in turn has kept the supply of skins for the leather industry fairly constant. Current predictions indicate that the supply of leather raw material will continue to follow the growth in population [1]. In developed countries a declining 'per capita' consumption of red meat has reduced the supply of skins and leather hides, while in the developing world, leather raw materials have become increasingly more available with over half of the world's supply originating in developing countries (Figure 1) [2].

An unwanted by-product of the global leather market is the waste generated during every stage in the lifecycle of leather and leather goods production. Recovery options exist for a small percentage of the waste generated, this includes: extraction of organic material for fertilisation and incineration of waste for energy recovery. However, a large proportion of the total leather waste is still sent to landfill with no material or energy recovery.

This paper explores the complex interdependent challenges faced when trying to implement a circular economy

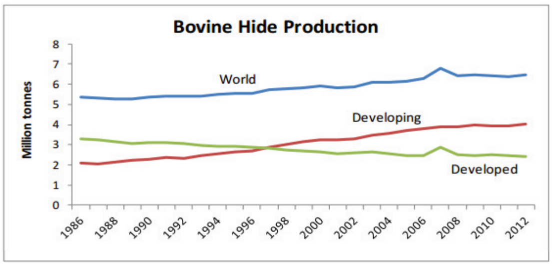

Figure 1: Increase in production of bovine hide [2]

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approach within the leather industry. These challenges range from achieving economy of scale required for commercial viability and finding secondary markets for the recycled materials to developing ‘resource efficient’ recycling processes that are tailored to the specific needs of leather products.

The work presented is an extension of research reported by Lee & Rahimifard (2010) on footwear recycling and aims to further develop and re-apply previous knowledge to a wider range of leather products.

One main outcome from previous work was that it is no longer economically feasible to think in silos when it comes to recycling individual product types. Recycling systems need to advance and adapt in order to allow the processing of multiple products with similar material content on the same line, which will provide enough scale to enable commercial viability.

The paper begins by presenting the lifecycle of leather along with an illustration of the waste generated at each stage. A review of the latest literature on the disposal of leather waste is performed along with an investigation into the key drivers for a material recycling system for leather. The key challenges in creating a leather material recycling system are investigated and the final section of this paper presents an analysis of all the considerations for creating a leather recycling system.

2. Lifecycle of leather

The lifecycle of leather is illustrated in Figure 2, along with examples of the waste generated at each stage in the lifecycle.

During the production of leather, animal skins undergo a series of operations in which a substantial quantity of solid waste is generated [3]. In a report by The World Bank, it was claimed that up to 70 % of the wet weight of the original hides can be wasted [4].

Wastes from tanneries include uniform waste streams such as wet blue trimmings and shavings (Figure 2 (a) and 2 (c)) and mixed waste streams, such as finished and dyed cuttings (Figure 2b). These wastes pose a serious threat to the environment and are an unavoidable by product of current tanning methods.

During the manufacturing stages finished leather hides are cut and formed into leather products such as footwear, apparel and furniture. The waste streams associated with this stage of the lifecycle include trimmings from the cutting of shaped leather pieces and prototype samples (Figure 2(d), 2(e) and 2(f)).

The next stage of the lifecycle includes the distribution and retailing of leather goods. Wastes associated with this stage include unsold stock, returned items from consumers including damaged items and seized counterfeit goods (Figure 2(g), 2(h) and 2(i)). Typically the number of different types of materials within this waste stream is high but the condition of the materials is often very good (excluding damaged items).

The final stage of the lifecycle is the post-consumer stage, where the consumer no longer needs or wants the leather products. This category of leather waste also includes a high-level of mixed material, however the quality and condition of materials are often very poor (Figure 2(j), 2(k) and 2(l)).

As you move through the lifecycle the waste stream becomes more diverse and complex, moving from mono-material ‘pure’ leather wastes in the tanneries to multi-

Figure 2: The lifecycle of leather and the waste associated with each stage

material product waste at the post-consumer stage, and the separation of leather from other materials becomes increasingly more challenging.

3. Current leather recovery options

The majority of leather waste is currently disposed of through landfill or incineration processes. Various other avenues exist for the recovery of the leather which includes three key areas of processing including mechanical, chemical and biological; these alternative options are mostly research scale. The selection of the leather recovery mechanism is often dependent on the stage in the lifecycle at which the waste is generated. The key methods of leather recovery are shown in Figure 3.

3.1 Biological processing

Various biological methods have been applied to the solid waste produced by tanneries with variable results. One type of biological process found within the literature is microbial fermentation, a process by which bacteria use waste as a medium to grow and produce useful by-products. Microbial growth on chromium-containing tannery shavings has been achieved, producing valuable protease by-product which has application in the pre-tanning process [5].

3.2 Chemical processing

Adhesives, films and chrome cake can be obtained from chrome tanned leather, splits, buffing dusts and trimmings. [6] Other novel chemical approaches include the use of organic chelates to remove chromium from leather waste [7], the production of pigments from chrome recovered from waste leathers [8] and the production of biodegradable hydrogels for packaging from collagen waste proteins. [9]

3.3 Mechanical processing

Mechanical methods for the utilisation of tannery wastes include any processing, such as fragmentation of wastes into small particles for incorporation into other materials as filler to produce recycled materials.

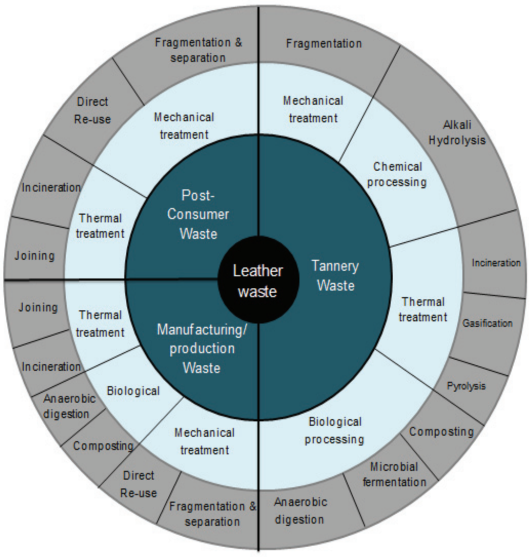

Figure 3: Avenues for recovery of leather waste throughout lifecycle

3.4 Thermal treatment

Thermal methods for treating tannery wastes include incineration, pyrolysis and gasification; through thermal treatment of waste it is possible to produce energy whilst also reducing the volume of waste substantially (up to 90%) [10]. Incineration of leather industry waste is garnering attention due to the restrictions on landfill and the increased global need for alternative energy sources.

4. Challenges in leather recycling

Landfilling and incineration of leather products results in significant economic and environmental losses. These can be prevented by designing industrial systems around circular concepts for consumption and recycling of leather products. The challenges in implementing such systems are explored in this section based on three key challenges of technology, secondary markets and economic viability, as illustrated in Figure 4.

4.1 Technology

Existing commercial lines based on current recycling technologies are not suitable for processing waste associated with the production of leather material or leather goods. To overcome this challenge two options are feasible: adapt existing processes to suit the waste feedstock or create new processes that are specifically tailored to the recycling of leather products. Whether improving technologies or creating new technologies, it is important to consider the effectiveness of the whole system. In order to maximise the effectiveness of any system, the following inter-linked system attributes need to be considered:

4.1.1 Throughput:

Typically classified as the rate of at which a job can be processed. Throughput within a leather recycling system will depend on the quality and type of feedstock. In order to separate out different types of materials from the input feedstock, the waste needs to be fragmented via granulation or shredding. A robust material like bovine leather will require more processing during the fragmentation phase than a softer material like goat leather. The range of material mix in the different waste inputs will impact the achievable throughput of the system; this should be considered when making decisions about technology solutions.

4.1.2 Value of recovered material:

Recycled material value is directly related to the quality or purity of the recyclate that the recycling system produces; value increases with an increase in material purity. The technology solution needs to be constantly adapted in order to match the desired output quality e.g. Low range <70%, mid-range 70-90% or high range >90% of purity.

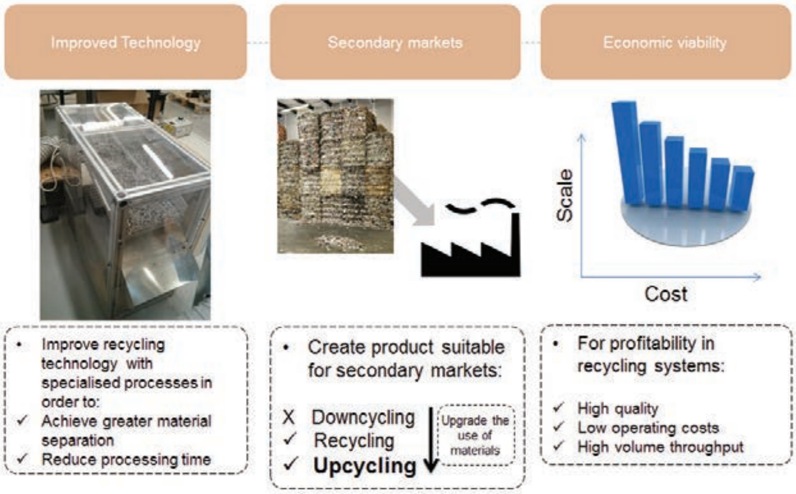

Figure 4: Three core challenges for implementing a leather recycling solution

If for instance, a client requires a low grade, low value recycled material to incorporate into running tracks or for producing carpet underlay, then the technology solution should be configured in such a manner that will produce the low grade material. Conversely, if the client requires a high-grade material for producing faux leather materials, then the recycling system will require upgrades to enable a higher-grade of material to be achieved.

4.1.3 *Resource efficiency:*

In order to recovery materials from leather waste, resources including energy and materials (in the form of operational consumables) will be used during processing. It is imperative that the environmental impact from the resources used for recovery do not exceed the environmental impacts from alternative disposal methods such as landfilling. When considering technology options for recycling leather then resource efficiency has to be a key consideration in the decision making process.

4.2 *Secondary markets*

In order to successfully implement a long-term sustainable leather recycling system there needs to be secondary markets for the recovered materials. This involves key challenges such as: understanding the physical properties of the recovered materials, along with any post-processing operations the waste material may require in order to meet the functional requirement specifications that customers have for their recycled raw materials.

In addition, it is imperative to consider the value of the recycled leather compared to alternative recycled materials on the market which could fulfill the same functional requirements. Value is a key issue for the economic viability of any scheme and hence must be carefully considered. In this context, three core categories of future use for recovered materials have been created and these are: downcycling, recycling and upcycling.

4.2.1 *Downcycling:*

Any secondary use of the recycled leather where the recovered value is less than the original value of the leather is considered to be downcycling. Downcycling also refers to the failure to fully recoup the embedded materials or energy from the recycled leather. Downcycling options include energy recovery methods such as incineration, and anaerobic digestion of solid waste when used to produce nutrient enriched effluents for agricultural purposes [11].

Other examples include the fragmentation of leather shavings to be used in the adsolubisation of organic contaminants from wastewaters [12]. These applications are novel and are economically advantageous compared with commercial materials that perform the same job; however, these uses still represent a down-cycling of the leather material and further problems are created with processing of the adsolubised waste material. Downcycling options should only be considered when the structural integrity of the leather product or material has been compromised and no further recovery option is possible.

4.2.2 *Recycling:*

The term ‘recycling’ is considered to represent any secondary use of the recycled leather that would achieve the same economic value as the original leather material. Materials such as reconstituted leather and the use of recycled leather for producing leather boards would be considered under this category.

Other recycling routes include the incorporation of powdered leather shavings into rubber compounds to improve the properties [13] and the inclusion of shavings and buffing dust into cavity insulation materials [14].

4.2.3 Upcycling:

The final route for leather recovery would be to upcycle the value of the material and use it to produce high quality, high value products. Processes that extract the embedded chemical compounds and other materials (gelatine and collagen) from the recycled leather are considered to be upcycling processes.

These processes include the microbial fermentation of tannery waste to recover chrome, which presents a potential in-house solution to the management of chrome shavings and the circular use of resources within the tannery [15].

Other chemical processes for the treatment of tannery waste involve alkali hydrolysis and result in the production of gelatine which has potential uses in cosmetics, printing and leather finishing. Reconstituted collagen has been produced which can be used in animal feed and as fertiliser and a re-tanning agent. [16]

4.3 Economic viability

One of the key driving factors for achieving economic viability within a recycling system is the quality or purity of the recovered material, this is the attribute that ultimately determines the value of the material; a higher purity material will command a higher price on a recycled materials market.

However, there are other considerations that will influence the profitability of a system including: the mass of material being processed (throughput), the original quality of the material (as this will determine how much processing is required to raise the quality- if required) and the operational costs associated with raising the purity level of the input feedstock. Factors that impact the operational costs of the system include: the mass and geographical distribution of the waste, transport costs, and any post-processing costs that will be incurred before the recovered leather material is suitable for use in a secondary product application, e.g. laboratory testing costs or fire-proofing coating. These economic factors are represented in equations (1), (2) and (3), which are used to calculate the revenue generated from a leather recycling system.

$$R_m = V_{m-} CP_{fs} \quad (1)$$

Where:

$$V_m = V_o \times M_o \quad (2)$$

$$CP_{fs} = (V_{fs} + C_p) \times M_{fs} \quad (3)$$

And:

R_m = System revenue (profit)

V_o = Value (£/tonne) of a specified purity of output material on a secondary market

V_{fs} = Cost (£/tonne) of procuring the waste material feedstock for processing

C_p = Cost (£/tonne) associated with processing the input stream, including consumables, energy, labour and other costs

M_{fs} = Mass (in tonnes) of the input waste feedstock to the system*

M_o = Mass (in tonnes) of material output from the system*

* The term *Mass* has been used instead of *weight* in order to accurately convey the units used by common scales (Kg and tonnes)

When considering the original state of the waste input stream, waste with a greater amount of impurities (i.e. contaminant materials not targeted for recovery) will require a greater amount of processing incurring greater processing costs and making the system less profitable.

Depending on the rate of increase in processing costs and the rate of increase in revenue (as the purity of the material increases), then this can make or break the profitability of a system.

Figure 5 illustrates that an increase in purity from 50% to 80% can, depending on value of materials (V_m) result in either a profit (a)-(b), or a loss (b)-(c). To drive the purity of the recovered leather towards a higher value makes economic sense only if there is adequate return on this processing investment. Depending on the exact value of the recovered materials and the fixed costs of processing then there is a distinct point at which the cost of processing no longer makes financial sense. This cost-benefit analysis serves as the most appropriate decision point when deciding if an increase in purity is financially viable.

5. Concluding remarks

It is clear to see that the creation of a leather recycling solution is a complex, multi-criteria problem. Involving a systematic evaluation of factors related to technology, secondary markets and economic viability; an already difficult feat compounded by the inter-connectedness of each of these attributes.

Before probing further into the key aspects of designing a

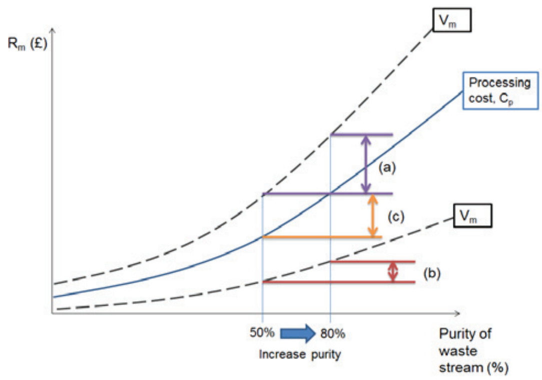

Figure 5: Increasing purity, processing costs Vs revenue

recycling solution, it is pertinent to first evaluate the root cause driver for creating such a circular system. Three commonly justified reasons for implementing recycling systems are:

- To mitigate any harmful effects of inappropriate disposal of hazardous wastes, e.g. battery recycling
- To recover some of the resources embedded in the product or material, e.g. paper and plastic
- When a resource is scarce or non-renewable, recycling helps to keep supply consistent e.g. critical metal recovery (Gold)

In the case of leather, the core driver for implementing a recycling system would be to eliminate or limit the negative environmental impacts that occur from sending chromium-tanned leather waste to landfill. This is closely followed by the need to maximize the return against the embedded resources within the leather goods; leather products generally have a high lifecycle impact due to the extensive processing and water use during tanning. It is less important to consider the scarcity of leather as a reason for recycling; due to the nature of the material, leather production is dictated by the consumption of meat and so there will be no scarcity of virgin leather if recycled leather is not produced.

The requirements for the system technology are dictated by the intended secondary application of the recycled material. Considering a three-category approach to disposal, namely: downcycling, recycling and upcycling provides a blueprint for system design. Each disposal route will require a unique combination of technologies in order to maximise system efficiency. And it is worth stating that it is crucial to upgrade leather disposal methods from current incineration efforts (where the only resource recovered is energy and at a small fraction of the embedded energy in the waste) to material recycling, to enable a better return on resources invested in the waste materials.

Finally, resource efficiency has a direct impact on the amount of water, energy and materials that are used during the recovery of the recycled leather material.

In conclusion, this paper presents a strong case for a material recycling solution for waste leather materials and leather products. In addition, it is argued that to ensure the realisation of a true circular use of resources, there is a need to achieve significant improvements in quality and yield of materials that are recovered from waste leather products. The specific challenges associated with achieving this have been examined and these have been recognised as the necessary attributes to meet the requirements of future recycling activities.

The practicality of implementing a leather recycling solution involves making decisions based on system throughput, desired material quality and the resource efficiency of individual technology solutions. The concepts of: technology improvement, creation and reconfigurability could all provide viable solutions dependent on system requirements.

6. Future work

Currently research is being undertaken to create decision-making tools that can assist with the design of recycling systems for leather. These tools will enable the core challenges of: increasing the adaptability of technology, designing secondary uses for recovered leather materials and creating economically viable systems to be addressed.

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