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Cleaner Production in the Tanning Industry: A Review of Case Studies and Sustainable Practices

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A B S T R A C T

The tanning industry, which is notorious for using a lot of resources and having an adverse effect on the environment, has been moving toward cleaner production (CP) methods. This review summarizes case studies from different nations, emphasizing the strategies used to lower pollution, increase resource efficiency, and abide by environmental laws. The tanning process, resource recovery technology, and cleaner production techniques are examples of approaches that have helped industry reduce waste and enhance sustainability. Notwithstanding advancements, difficulties still exist, especially in implementing widely used cleaner technology and striking a balance between financial concerns and environmental stewardship. The study discusses specific cleaner production technologies and techniques that have been effectively implemented, such as the use of plant-based ingredients, chrome-free substitutes, and enzyme-based tanning. By increasing resource efficiency, these solutions not only lower the loads of hazardous waste and wastewater, but they may also result in cost savings. The growing importance of nanotechnology and sophisticated filtration methods, like membrane-based procedures, which hold promise for further lowering pollution and improving resource recovery, are also included in this review

The study focuses on effective case studies, persisting challenges, and potential paths forward for the tanning industry's cleaner production.

Keywords: Tanning industry, Cleaner Production, Resource Recovery, Chrome free substitutes, Nanotechnology

INTRODUCTION

The leather tanning sector plays a significant role in the world economy, particularly in developing countries where it creates a lot of jobs and generates export income. However, the sector is also one of the most polluting, notably due to its reliance on toxic chemicals such as chromium and excessive water consumption during various phases of leather manufacturing. Tanning has been linked to a number of well-documented environmental problems, including air pollution, hazardous effluent discharge, water contamination and solid waste generation,

Cleaner Production (CP) techniques have been pushed as a way to lessen the tanning industry's negative environmental effects while preserving its commercial viability in response to these issues. CP is a proactive approach to environmental management that aims to reduce emissions and waste at the source by utilizing innovative technology, better operating procedures, and more resource efficiency. In order to incorporate CP into the tanning industry, new tanning agents must be adopted, water and chemical usage must be optimized, effluent must be recycled, and valuable byproducts like biogas and chromium must be recovered.

Through the analysis of case studies from diverse geographic locations, this paper seeks to evaluate the current status of CP implementation in the tanning sector. The various methods to CP that are highlighted in these case studies include resource recovery systems, sophisticated tanning procedures, and pollution avoidance strategies**.** This paper offers an extensive understanding of how CP might be used to the tanning sector, the potential advantages of such methods, and the obstacles to their general implementation by examining the successes and difficulties reported in these case studies. The study also highlights how crucial it is to have financial incentives, legal support, and technical advancements to speed up the leather industry's adoption of CP practices.

LITERATURE STUDY

Padda, I. U. H., & Asim, M. (2019). The study aims to identify the impact of a cleaner production program on the leather industry in Sialkot, Pakistan, and other determinants. The data was analyzed using Poisson regression analysis and found no significant impact in 2015. However, the effect of cleaner production support by CPC on practices diminished once support ended. Factors such as firm size, financial position, international and regulatory pressures, export orientation, and enforcement of environmental compliance laws were found to be major determinants of adoption. Compliance with cleaner production measures was low, with 6.4 out of 19 practices being implemented. The study suggests the need for environmentally friendly measures that promote labor health and product quality, which are crucial for the sustainable growth of the tanning industry

Rivela, B., Méndez, R., Bornhardt, C., & Vidal, G. (2004) The study examines a Chilean leather tannery's input/output (I/O) of beamhouse, tan yard, and re tanning operations, as well as the physical and chemical characterisation of 19 effluent streams. A 19-step approach was used to assess pollution prevention, following UNEP/UNIDO recommendations .The process involved assessing organic content, pH levels, and presence of contaminants such as sulphur and chromium in wastewater streams .The study emphasizes the importance of cleaner production practices for reducing pollution and environmental damage .The proposed methods focus on lowering water and chemical use, along with specific treatment strategies for chromium and sulfur-containing wastewaters.

Mhlanga, S., Goriwondo, W. M., & Tapedzisa, C. (2010) The paper emphasizes the importance of sustainable resource usage, recognizing the finite nature of resources and the duty to future generations.The article explores how smaller enterprises in developing nations with limited access to modern technologies are adopting environmentally friendly production practices .The methodology uses Cleaner Production (CP) concepts to reduce environmental hazards in a medium-scale tannery. It focuses on alternative processing strategies to improve efficiency and minimize environmental effect .The case study demonstrates how CP approaches can improve resource use and process efficiency while complying with environmental standards .The conclusion emphasizes the importance of lowering chrome usage and improving management control over environmental factors, arguing for a change toward source reduction and investment in cleaner production

Al-Jabari, M., Sawalha, H., Pugazhendhi, A., & Rene, E. R. (2021). This review explores cleaner production options for leather manufacturing industries and proposes resource recovery technologies.. It examines raw materials, processing parameters, and effluent composition in local tanneries in Palestine. The most practical method is to change the tanning process settings to boost efficiency. The assessment also looks at several technological alternatives for recovering resources from leather industry wastewater and solid waste, such as biogas, chromium, lipids, and chemicals.

Dandira, V., Mugwindiri, K., & Chikuku, T. (2012). The study examines environmental contamination challenges in leather manufacturing, highlighting the need for Cleaner Production (CP) to reduce waste and enhance efficiency. It focuses on the widespread use of chemicals in the tanning process, which adds to pollution.The process comprises the evaluation of CP solutions, emphasizing on lowering salt in effluents by including a chilling unit. The study found that firms frequently prioritize productivity over pollution prevention, resulting in increasing waste.The conclusion is that implementing CP techniques can lead to economic savings and a better environment, while also addressing the challenges of obsolete processes and technologies

Suresh, V., Kanthimathi, M., Thanikaivelan, P., Rao, J. R., & Nair, B. U. (2001). The paper discusses about the new chrome syntan has been developed to reduce pollution in tannery effluents by over 90%. This improved product serves as both a tanning and retanning agent, eliminating the need for conventional pickling in leather processing. The modified process reduces chemical oxygen demand, total dissolved solids, and chlorides in the spent tan liquor by 51, 81, and 99%, respectively. The product offers full, soft leathers with shrinkage temperatures comparable to conventional chrome tanned skins. The highly reactive product saves time and reduces water requirements compared to conventional tanning methods, making it both environmentally friendly and economically viable.

Van Berkel, C. W. M. (1999) The study describes a structured approach to Cleaner Production that emphasizes employee participation and management commitment. It emphasizes the need of cost awareness and planned assessments in identifying and implementing Cleaner Production opportunities successfully. Cleaner Production is an effective technique for decreasing waste and emissions, with large economic gains achieved by preventing waste at its source. The experiences of small to medium-sized firms show that, despite hurdles, significant financial and environmental gains are feasible through Cleaner Production practices

Marsal, A., Cuadros, S., Ollé, L., Bacardit, A., Manich, A. M., & Font, J. (2018) The paper examines different formaldehyde scavengers, including plant extracts like Vinca rosea and Camellia sinensis, as well as chemicals like sodium bisulphite and hydroxylamine sulphate, which have demonstrated success in lowering free formaldehyde in leather manufacture. The article emphasizes the environmental impact of formaldehyde and the necessity for safer leather manufacturing procedures to prevent dangerous compounds. The methodology tests the effectiveness of mimosa extract and gallic acid as scavengers in reducing formaldehyde concentration in leather.The results demonstrate that hydroxylamine is hazardous and its efficiency reduces over time, whereas gallic acid offers promise as a safer option. The study concluded that while numerous scavengers can reduce formaldehyde levels, the quest for environmentally acceptable solutions continues, with gallic acid emerging as a possible choice for cleaner leather manufacturing.

Muthukrishnan, L. (2021). The study discusses about the leather industry, a major global business, is facing issues such as raw hide scarcity, ethical concerns, competitive replacements, and environmental legislation. Nanotechnology can assist solve these problems by developing new goods and treating tannery effluents. This article examines research gaps in traditional leather manufacturing processes such as curing, tanning, and effluent treatment using nano tannage, photocatalysts, and filtering. Nanomaterials have been used to increase performance.

Nalyanya, K. M., Rop, R. K., Onyuka, A. S., & Birech, Z. (2021) The study analyzes several studies on the use of natural plants in leather tanning, with a focus on how they affect the quality of leather products. Environmental regulations have led to a shift away from synthetic chemicals and towards eco-friendly alternatives. The methodology entails gathering existing literature on plant extracts used in various phases of leather manufacturing, such as tanning and dyeing, and evaluating their physical qualities. The conclusion emphasizes the effectiveness of natural plants in improving the physical and organoleptic aspects of leather, such as tensile and tear strength. However, it also emphasizes the need for additional research to ensure the safety and quality of these plant-based alternatives, as well as to investigate viable extraction methods.

Kanth, S. V., Venba, R., Madhan, B., Chandrababu, N. K., & Sadulla, S. (2009) The paper studies environmentally friendly vegetable tanning technologies that use enzymes to reduce pollutants from traditional tanning procedures. The technology employs a pickle-free enzymatic tanning process, resulting in over 95% tannin exhaustion, a 10% improvement over standard methods .The study focuses reducing TDS, chlorides, and COD in effluent for better environmental effects .To summarize, the enzymatic technique not only improves leather quality but also dramatically reduces pollution loads, making it a viable option for sustainable leather production.

Nazer, D. W., & Siebel, M. A. (2006) The study discusses the enormous environmental impact of the leather tanning industry, especially in Palestine, where tanneries contribute to pollution through high chemical usage and wastewater outflow. The proposed approach for unhairing eliminates the need for chemicals and generates less wastewater by recycling process water The methodology involves lab-scale tests and life cycle assessment (LCA) to measure environmental benefits, and a present value approach for economic feasibility. Results suggest that the redesigned approach can drastically reduce chemical emissions like COD by 50%, sulfide by 73%, and overall environmental effect by 24% when recycling water four times. The study found that the updated strategy not only reduces environmental expenses but also generates economic savings, even with initial investments in new equipment. 12

Wu, J., Zhao, L., Liu, X., Chen, W., & Gu, H. (2017) The literature study focuses on the transition from traditional sodium chloride (SC) curing to alternate approaches for preserving hides and skins. Various strategies, such as natural plant preservatives, chemical compounds, and advanced physical processes, are being investigated to reduce SC reliance and environmental impact. The review highlights the benefits of using SC, silica gel, and chilling to preserve leather quality and reduce pollution.In conclusion, while there are several preservation methods available, none are perfect. Environmental regulations are driving the development of eco-friendly and economically feasible alternatives to SC curing. The assessment recommends more research into new preservation procedures that meet both quality and sustainability standards.

Masoud, M. (2021) The literature study discusses several cleaner production options in the leather tanning business, highlighting the necessity to improve chromium uptake while reducing environmental effect. Recommendations include improving collagen-chromium interactions, collecting wastewater for chromium recovery, and building composting plants to manage solid waste. The process entailed building a lab-scale tanning drum to test traditional tanning procedures with changing chromium concentration and water temperature. The trials investigated chromium uptake and leather quality, indicating ideal conditions at 25°C and 5.5% chromium content, attaining 95.33% uptake.Finally, the study concludes that improving chromium uptake is the most realistic cleaner production alternative for Palestinian tanneries, implying that improvements in tanning conditions can lead to improved environmental practices.

Buriticá, N. C., JR, L. C. L., & Rodríguez, S. (2012). The use of functional polymers in the leather industry to support greener production practices is examined in this research. The technique comprised a methodical review of the literature, gathering pertinent publications and eliminating less relevant sources to concentrate on polymer uses in different stages of the leather manufacturing process, such as pre-tanning and tanning. Important topics covered include amphoteric polymers and organic sulphydryl compounds, which take the place of dangerous chemicals that are typically employed in the leather manufacturing industry. The results show that these polymers can improve tanning process efficiency and lower environmental pollutants, which will ultimately lead to a more sustainable leather business.

Ebabu, W., Israil Hossain, M., El-Naggar, M. E., Kechi, A., Hailemariam, S. S., & Ahmed, F. E. (2022). The review paper focuses on the usage of polymers in the leather manufacturing process in order to reduce environmental waste. The methodology involved a systematic literature review, which included searching various digital libraries for relevant articles, excluding less related literature, and analyzing the gathered data for a comprehensive understanding of polymer applications in pre-tanning, tanning, post-tanning, and finishing processes.In conclusion, the use of polymers, notably amphoteric and polyurethane, considerably improves the tanning process while reducing pollution from previous methods. This transition to polymeric materials constitutes a critical step toward cleaner production in the leather industry.

Rajamani, S. (2018). The literature study emphasizes the necessity for the fashion and clothing sector to rethink sustainable growth methods in the face of increased competition and shorter product life cycles. The study used a structured questionnaire and theoretical analysis to analyze employee satisfaction in the textile industry. It included 241 respondents from Serbian textile businesses. The study found that a substantial majority of respondents were neither satisfied nor unsatisfied with cooperation, indicating a lack of organized collaboration, which is vital for corporate success. The conclusion underlines that knowing fashion trends and consumer needs, together with new approaches, can lead to successful product diversification and market awareness.

Madanhire, I., & Mbohwa, C. (2015)The study examines the physicochemical properties of effluent from leather manufacture, specifically contaminants from goat and cow hides The methodology involves evaluating parameters such as pH, COD, total solids, and chromium content in effluents from nearby tanneries .The liming method yields the maximum COD, whereas chromium levels in tanning wastewater are below acceptable limits .The study indicates that appropriate treatment of chromium-containing wastewater is critical due to the environmental implications and regulatory demands. 18

Ahmed, D., Maraz, K. M., & Khan, R. A. (2021) The research includes evaluating the effects of ultrasound on chromium uptake and skin shrinking throughout the tanning process, with considerable improvements in both areas. The conclusion highlights that shifting to vegetable tanning or including ultrasound in chrome tanning can reduce environmental impacts, making these technologies viable for sustainable leather production.

Al-Houriny, H., & Nammoura, I. (2020). The literature study focuses on Cleaner Production (CP) methods used in the leather tanning industry to reduce environmental effect. These include alternative tanning chemicals and improved techniques to improve chromium recovery .The study sampled and tested effluent from Hebron tanneries to assess factors such as COD, pH, and chromium levels .The study indicated that wastewater from several tanning procedures differed significantly in pH and pollutant loads, with the liming and unhairing process producing the greatest COD .The result underlines the significant pollutant load in the wastewater, with around 10m³ created every ton of hide treated. This highlights the need for enhanced waste management procedures in the business.

Giannetti, B. F., Agostinho, F., Moraes, L. C., Almeida, C. M., & Ulgiati, S. (2015) The study analyzes the environmental consequences of chromium-based tanning procedures, emphasizing the necessity for cleaner production methods. This study evaluates the unhairing/liming, pickling/tanning, and wastewater treatment procedures in tanneries using a multicriteria, multiscale methodology that includes materials balance, economic analysis, and energy accounting. The methodology compares two scenarios, one without and one with recycling, using basic index comparisons and radar graphs to assess performance. The findings show that recycling solutions can dramatically cut water and chemical use while boosting electricity demand. The conclusion emphasizes that while recycling is economically beneficial, improvements in tanning methods are required to boost sustainability and renewability.

Al Sharabaty, R., & Sarsour, S. (2017) The study examines the physicochemical properties of effluent from leather manufacture, specifically contaminants from goat and cow hides .The methodology involves evaluating parameters such as pH, COD, total solids, and chromium content in effluents from nearby tanneries.The liming method yields the maximum COD, whereas chromium levels in tanning wastewater are below acceptable limits .The study indicates that appropriate treatment of chromium-containing wastewater is critical due to the environmental implications and regulatory demands.

Cui, L., & Qiang, X. (2019) The research studies a unique chrome-free tanning procedure that employs a triazine molecule derived from cyanuric chloride, sulfanilic acid, and p-hydroxybenzaldehyde. The process involves assessing the tanned leather's physicochemical properties, such as heat stability and mechanical strength, and comparing them to traditional chrome-tanned leather. The results reveal that the triazine compound tanned leather has similar qualities to chrome-tanned leather while dramatically decreasing environmental impact, including decreased BOD, COD, and other pollutants.The conclusion highlights the commercial feasibility and environmental benefits of this approach, making it an attractive option for sustainable leather production.

Drioli, E., & Cassano, A. (2023) The study examines several membrane-based processes, particularly pressure-driven technologies such as microfiltration, ultrafiltration, nanofiltration, and reverse osmosis, for treating wastewater in the leather industries. It focuses on integrating new technologies with conventional treatments to improve efficiency and resource recovery.The results show that membrane operations greatly increase water recovery and resource reuse, particularly in the beam house and tanning processes. They successfully minimize pollutants and improve leather quality while remaining cost-effective. Integrating these methods with existing treatments can significantly reduce organic and inorganic contaminants, promoting sustainable practices in the leather sector.

Pradeep, S., Sathish, M., Sreeram, K. J., & Rao, J. R. (2021) The study covers the environmental and economic issues of conventional chromium tanning in leather production, including the generation of chromium waste and its accompanying dangers. It introduces a unique formaldehyde-free chromium-incorporated polymeric tanning agent (FF-CIPTA), which aims to reduce chromium input and solid waste creation. The technology comprises synthesizing FF-CIPTA from melamine, formic acid, and glyoxal, followed by characterisation with FT-IR and TGA.The experimental results reveal a significant reduction in wastewater volume (51.6%) and chromium input (71.4%), resulting to cheaper treatment costs and greater economic value for chromium-free leather scraps.The study shows that the FF-CIPTA approach not only improves leather quality but also encourages sustainable practices in the leather sector, generating a cumulative economic gain of US$ 39.84 per ton of raw material processed

Awulachew, M. T. (2021) This paper discusses the hazardous tannery effluent, a major industrial byproduct, and its impact on water resources. The tanning industry, which transforms animal hides into leather, produces high amounts of water and chemicals, leading to wastewater pollution. Tannery wastewaters are characterized by high salinity, organic loading, and specific pollutants like sulfide and chromium. Three types of wastes are discharged during tanning processes: air, water, and solid pollutants. Uncontrolled release of tannery effluents into natural water bodies increases health risks and environmental pollution. The paper emphasizes the need for environmentally safe waste management in the tanning manufacturing process to reduce environmental pollution risks.

Purba, F., Suparno, O., & Suryani, A. (2020) The study measures Green Productivity (GP) in the Indonesian leather-tanning business through a systems approach that incorporates direct observation, interviews, and waste analysis.The methodology included generating the Green Productivity Index (GPI) and examining environmental and economic variables to identify causes of wastes.The Analytical Hierarchy Process (AHP) was used to identify alternatives for increasing GP by combining GPI ratios and expert opinions. The study indicates that both tanneries had low GP due to high water consumption, and the greatest optimization approach discovered was water recycling in soaking and liming operations.

Rajamani, S. G., & Mulder,(2022) The literature study emphasizes the difficulties the leather tanning industry has, especially with regard to high salinity and Total Dissolved Solids (TDS) in effluents, which call for more environmentally friendly production methods and long-term treatment solutions . The concept comprises using novel desalting processes, separating saline streams, and modern treatment systems to recover quality salt and chromium, establishing a circular economy. The conclusion highlights considerable reductions in water usage and pollution discharge, resulting in a more sustainable leather production process and compliance with environmental requirements.

Kanagaraj, J., Velappan, K. C., Babu, N. K., & Sadulla, S. (2006) The study focuses on the leather business, which generates large solid and liquid waste, causing environmental degradation from hazardous chemicals and organic elements used in processing [1]. The review identifies different types of solid wastes, including raw trimmings, fleshing, chrome shavings, and buffing dust, and investigates their potential reuse in diverse applications.The study suggests that converting solid waste into valuable goods such as glue, gelatin, and chicken feed can reduce pollution and improve resource use.The conclusion emphasizes the necessity for comprehensive waste management methods to solve the pollution challenges created by solid wastes in the leather sector, as well as the development of technology that can convert these wastes into useful resources.

Klein, R. M., Hansen, É., & de Aquim, P. M. (2022) The study examines how the leather business confronts considerable environmental issues due to excessive water and chemical usage, notably in the post-tanning step, which generates diverse and less biodegradable waste.This study aims to investigate the reuse of treated wastewater (primary and secondary effluents) in the post-tanning process to reduce water consumption and outflow. The methodology included assessing water streams, conducting pilot-scale testing, and analyzing residual baths for several parameters. The results indicated that it was possible to reuse both primary and secondary effluents efficiently, ensuring the produced leather maintained its quality despite increasing salinity levels.

Ali, A., Shaikh, I. A., Ahmad, S. R., Shakoor, M. B., Yong, J. W. H., Rizwan, M., & Samina, F. (2024) The research focuses on increasing water efficiency and minimizing waste in the leather chemicals sector, namely at the Syntan plant and application laboratory in Lahore, Pakistan. It uses best available methods (BATs) such water gauging, pressurized vessel washing, and water reuse to reduce consumption and generate less effluent. The technology involves treating reduced wastewater by electrochemical processes such as electrocoagulation and electro-Fenton, resulting in significant reductions in water use and effluent discharge. Results show a 12.8%-100% reduction in effluent and a 46.7% drop in soft cooling water use . The research suggests that these sustainable methods can serve as a paradigm for improving water efficiency and resolving environmental concerns in the chemical industry.

Ricky, R., Shanthakumar, S., Ganapathy, G. P., & Chiampo, F. (2022) The review examined original research papers on Zero Liquid Discharge (ZLD) in the tannery industry from 2000 to 2022, using Scopus database and keywords such as "tannery," "cleaner," "RO," and "ZLD". The ZLD system uses a variety of technologies, such as reverse osmosis (RO) for desalination, thermal evaporation for salt separation, and pre-treatment systems for traditional physicochemical treatment.Despite constraints such as high running costs and energy consumption, the study demonstrates that ZLD is an important wastewater treatment approach around the world. It underlines the necessity for appropriate techniques to manage RO reject water and the economic consequences of solid waste disposal from ZLD systems.

Yuvaraj, A., Karmegam, N., Ravindran, B., Chang, S. W., Awasthi, M. K., Kannan, S., & Thangaraj, R. (2020). The study highlights the environmental impact of leather industry waste, which contains dangerous compounds such as heavy metals and causes significant soil and groundwater issues.The methodology focuses on eco-friendly vermiremediation utilizing earthworms to remediate leather wastewater sludge, highlighting the importance of earthworms and microorganisms in removing harmful chemicals. pH, humidity, and temperature are highlighted as important factors in boosting earthworm activity. The conclusion suggests that vermi-treated leather waste can function as a plant growth promoter, contributing sustainable agriculture and enhanced agroecosystems.

Chowdhury, Z. U. M., Ahmed, T., & Hashem, M. A. (2017) The study uses Energy and Material Flow Analysis (EMFA) to compare the life cycle of Full Chrome Leather (FCL) produced in Bangladesh to Indian leather production Data collected covers rawhide consumption, water and steam usage, chemical requirements, solid waste generation, and power consumption .The methodology uses a cradle-to-gate analysis to evaluate input and output characteristics and determine resource efficiency Bangladeshi FCL uses twice as much water as Indian leather, while Indian leather consumes more power .The research reveals that there are considerable differences in material and energy fluxes, highlighting potential to increase resource efficiency in leather production.

Daba, O., & Jilcha,(2022) The literature review examines diverse waste management approaches and their consequences for sustainability, highlighting the importance of successful trash reduction strategies in metropolitan areas.The study takes a qualitative approach, analyzing case studies and literature to find effective waste management strategies and their environmental effects.Research indicates that combining community participation and innovative technologies can considerably improve trash management efficiency.The conclusion emphasizes the need of implementing sustainable waste management strategies to reduce environmental concerns and increase public health.

CONCLUSION

The implementation of Cleaner Production practices is now absolutely important for the long-term viability of the global tanning business, and it is a significant turning point in the industry's history. CP offers many benefits, such as significant reductions in water and chemical usage, enhanced waste management, and less environmental pollution, according to the study of case studies reported in this research. The employment of natural plant-based substitutes, chrome-free tanning techniques, and enzyme-based tanning have shown promise in enhancing the financial and environmental performance of tanneries.Nonetheless, there is still disparity in the industry's widespread application of CP. Larger companies and wealthy nations have made great strides, but small and medium-sized tanneries, especially those in developing nations, still face many obstacles. These include inadequate enforcement of regulations, expensive expenses associated with new technology, and a lack of technical know-how. In addition, many tanneries are unable or unwilling to make the significant financial and capacity-building investments necessary for the switch to CP without outside assistance.We need to use a diversified approach to address these issues. Particularly in areas where CP adoption is trailing, governments and international organizations must offer tanneries financial incentives and technical assistance. Industry groups should be essential in sharing best practices and promoting technology transfer, and regulatory frameworks should be reinforced to guarantee adherence to environmental requirements. To establish an environment that is favorable for the implementation of CP, cooperation between stakeholders—including tannery owners, researchers, legislators, and environmental organizations will be essential.

In conclusion, the case studies examined in this research provide useful insights into the paths to sustainable leather production. While obstacles remain, accomplishments from many countries offer a template for how the tanning business might become environmentally friendly, efficient, and ecologically responsible. Continued innovation, together with strong governmental and financial backing, will be critical to guaranteeing the tanning industry's global shift to cleaner production. Through collaborative efforts, the industry may not only accomplish environmental goals, but also improve its long-term sustainability and competitiveness in the global market.

REFERENCES:

1. Padda, I. U. H., & Asim, M. (2019). What determines compliance with cleaner production? An appraisal of the tanning industry in Sialkot, Pakistan. *Environmental Science and Pollution Research*, *26*(2), 1733-1750. https://doi.org/10.1007/s11356-018-3717-0
2. Rivela, B., Méndez, R., Bornhardt, C., & Vidal, G. (2004). Towards a cleaner production in developing countries: a case study in a Chilean tannery. *Waste management & research*, *22*(3), 131-141. https://doi.org/10.1177/0734242x04044322
3. Mhlanga, S., Goriwondo, W. M., & Tapedzisa, C. (2010). Cleaner Production Techniques for Mitigation of Tannery Waste: Case Study ABC. Engineers Without Borders International Conference.
4. Al-Jabari, M., Sawalha, H., Pugazhendhi, A., & Rene, E. R. (2021). Cleaner production and resource recovery opportunities in leather tanneries: Technological applications and perspectives. *Bioresource Technology Reports*, *16*, 100815. https://doi.org/10.1016/j.biteb.2021.100815
5. Dandira, V., Mugwindiri, K., & Chikuku, T. (2012). A cleaner production exercise of a leather manufacturing company: a zimbabwean experience. *International Journal of Scientific & Technology Research*, *1*(11), 1-5.
6. Suresh, V., Kanthimathi, M., Thanikaivelan, P., Rao, J. R., & Nair, B. U. (2001). An improved product-process for cleaner chrome tanning in leather processing. *Journal of Cleaner Production*, *9*(6), 483-491. https://doi.org/10.1016/s0959-6526(01)00007-5
7. Van Berkel, C. W. M. (1999). Cleaner production: a profitable road for sustainable development of Australian industry. *Clean Air and Environmental Quality*, *33*(4), 33-38.
8. Marsal, A., Cuadros, S., Ollé, L., Bacardit, A., Manich, A. M., & Font, J. (2018). Formaldehyde scavengers for cleaner production: a case study focused on the leather industry. *Journal of cleaner production*, *186*, 45-56. https://doi.org/10.1016/j.jclepro.2018.03.109
9. Muthukrishnan, L. (2021). Nanotechnology for cleaner leather production: a review. *Environmental Chemistry Letters*, *19*(3), 2527-2549. https://doi.org/10.1007/s10311-020-01172-w
10. Nalyanya, K. M., Rop, R. K., Onyuka, A. S., & Birech, Z. (2021). A review of natural plants as sources of substances for cleaner leather tanning technologies. *Textile & Leather Review*, *4*(3), 137-148. https://doi.org/10.31881/tlr.2021.03
11. Kanth, S. V., Venba, R., Madhan, B., Chandrababu, N. K., & Sadulla, S. (2009). Cleaner tanning practices for tannery pollution abatement: role of enzymes in eco-friendly vegetable tanning. *Journal of Cleaner Production*, *17*(5), 507-515. https://doi.org/10.1016/j.jclepro.2008.08.021
12. Nazer, D. W., & Siebel, M. A. (2006). Reducing the environmental impact of the unhairing–liming process in the leather tanning industry. *Journal of cleaner production*, *14*(1), 65-74. https://doi.org/10.1016/j.jclepro.2005.04.002
13. Wu, J., Zhao, L., Liu, X., Chen, W., & Gu, H. (2017). Recent progress in cleaner preservation of hides and skins. *Journal of Cleaner Production*, *148*, 158-173. https://doi.org/10.1016/j.jclepro.2017.01.113
14. Masoud, M. (2021). *Technical Feasibility of Applying Cleaner Production Practices in Palestinian Leather Tanning Industry* (Doctoral dissertation, جامعة النجاح الوطنية).
15. Buriticá, N. C., JR, L. C. L., & Rodríguez, S. (2012). Environmental Management of the Tanning Industry's supply Chain: An Integration Model from Lean Supply Chain, Green Supply Chain, Cleaner Production and ISO 14001: 2004. *International Journal of Industrial and Manufacturing Engineering*, *6*(10), 2281-2288.
16. Ebabu, W., Israil Hossain, M., El-Naggar, M. E., Kechi, A., Hailemariam, S. S., & Ahmed, F. E. (2022). Exploration of functional polymers for cleaner leather industry. *Journal of Inorganic and Organometallic Polymers and Materials*, 1-14. https://doi.org/10.1007/s10904-021-02129-4
17. Rajamani, S. (2018). Viable Environmental Technologies integrated with Cleaner Production-Sustainable Options for Global Leather Sector. *FASCICLE OF TEXTILES, LEATHERWORK*, 143.
18. Madanhire, I., & Mbohwa, C. (2015, December). Cleaner production as a tool to mitigate pollution in leather processing: Case study. In *2015 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM)* (pp. 30-33). IEEE. https://doi.org/10.1109/ieem.2015.7385602

19. Ahmed, D., Maraz, K. M., & Khan, R. A. (2021). Prospects and challenges of chrome tanning: approach a greener technology in leather industry. *Scientific Review*, *7*(3), 42-49. https://doi.org/10.32861/sr.73.42.49

20. Al-Houriny, H., & Nammoura, I. (2020). Wastewater characterization towards cleaner production in leather tanning industry in Palestine.

21. Giannetti, B. F., Agostinho, F., Moraes, L. C., Almeida, C. M., & Ulgiati, S. (2015). Multicriteria cost–benefit assessment of tannery production: The need for breakthrough process alternatives beyond conventional technology optimization. *Environmental Impact Assessment Review*, *54*, 22-38. https://doi.org/10.1016/j.eiar.2015.04.006

22. Al Sharabaty, R., & Sarsour, S. (2017). Leather Manufacturing Wastewater Characterization and Cleaner Production Options.

23. Cui, L., & Qiang, X. (2019). Clean production for chrome free leather by using a novel triazine compound. *Journal of Renewable Materials*, *7*(1), 57-71. https://doi.org/10.32604/jrm.2019.00118

24. Drioli, E., & Cassano, A. (2023). Membranes and integrated membrane operations as clean technologies in the leather industry. *Clean Technologies*, *5*(1), 274-296. https://doi.org/10.3390/cleantechnol5010016

25. Pradeep, S., Sathish, M., Sreeram, K. J., & Rao, J. R. (2021). Melamine-based polymeric crosslinker for cleaner leather production. *ACS omega*, *6*(20), 12965-12976.

26. Awulachew, M. T. (2021). A review of pollution prevention technology in leather industry. *Environ Pollut Climate Change*, *5*(244), 2.

27. PURBA, F., SUPARNO, O., & SURYANI, A. (2020). Green productivity in the indonesian leather-tanning industry. *Revista de Pielarie Incaltaminte*, *20*(3), 245. https://doi.org/10.24264/lfj.20.3.4

28. RAJAMANI, S. G., & MULDER, A. ECOLOGICAL FRIENDLY PRODUCTION PROCESS AND WASTE TREATMENT FOR CIRCULAR ECONOMY IN LEATHER TANNING INDUSTRIES. https://doi.org/10.24264/icams-2022.iv.11

29. Kanagaraj, J., Velappan, K. C., Babu, N. K., & Sadulla, S. (2006). Solid wastes generation in the leather industry and its utilization for cleaner environment-A review. https://doi.org/10.1002/chin.200649273

30. Klein, R. M., Hansen, É., & de Aquim, P. M. (2022). Water reuse in the post-tanning process: minimizing environmental impact of leather production. *Water Science and Technology*, *85*(1), 474-484. https://doi.org/10.2166/wst.2021.620

31. Ali, A., Shaikh, I. A., Ahmad, S. R., Shakoor, M. B., Yong, J. W. H., Rizwan, M., & Samina, F. (2024). Application of effluent reduction methods and treatment using advanced oxidation process at leather chemicals and tanning industries. *Frontiers in Environmental Science*, *12*, 1422107. https://doi.org/10.3389/fenvs.2024.1422107

32. Ricky, R., Shanthakumar, S., Ganapathy, G. P., & Chiampo, F. (2022). Zero liquid discharge system for the tannery industry—an overview of sustainable approaches. *Recycling*, *7*(3), 31. https://doi.org/10.3390/recycling7030031

33. Yuvaraj, A., Karmegam, N., Ravindran, B., Chang, S. W., Awasthi, M. K., Kannan, S., & Thangaraj, R. (2020). Recycling of leather industrial sludge through vermitechnology for a cleaner environment—A review. *Industrial Crops and Products*, *155*, 112791. https://doi.org/10.1016/j.indcrop.2020.112791

34. Chowdhury, Z. U. M., Ahmed, T., & Hashem, M. A. (2017). Materials and energy flow in the life cycle of leather: a case study of Bangladesh. *Matériaux & Techniques*, *105*(5-6), 502. https://doi.org/10.1051/mattech/2018013

35. Daba, O., & Jilcha, K. GREEN SUPPLY CHAIN ADAPTATION IN LEATHER MANUFACTURING INDUSTRY: CASE STUDY IN ETHIOPIAN TANNERY S. CO. https://doi.org/10.1007/s13132-024-02180-9