Proceedings of the
International Conference on Mechanical Engineering and Renewable Energy 2015
(ICMERE2015) 26 – 29 November, 2015, Chittagong, Bangladesh

ICMERE2015-PI-213

COMPARATIVE EVALUATION OF ENVIRONMENTAL IMPACT OF LEATHER PROCESS USING LCA METHODOLOGY

Zia Uddin Md. Chowdhury[1,*], Md. Ariful Islam Juel[2] and Hira Lal Paul[3]

[1,2]Department of Leather Engineering,
Khulna University of Engineering & Technology, Khulna-9203, Bangladesh
[3]Institute of Creative Leather Technologies, University of Northampton, London, United Kingdom
[1,*]zia1.chowdhury@yahoo.co.uk, [2]juel_islam@le.kuet.ac.bd , [3]hiralal_paul@yahoo.com

Abstract*- The environmental impact of leather is an area of increasing interest for consumers and legislators. Life cycle assessment (LCA) is the commonly used decision support tool for quantifying and evaluating environmental impacts. This paper constructed inventory of pretannage process carried out by aluminum and chromium tanning agents as a basis to analyze, compare and propose further improvement actions. The functional unit is 1 square meter leather and impact assessment conducted based on IMPACT 2002+methodology. In this method, data inventoried and assembled according to life cycle assessment (LCA) methods principle and requirements of ISO-14040/44, 14067 standards. All procedure carried out using leading LCA software SimaPro. Results indicated that, Aluminium pretannage process has more than 13 times higher impact on aquatic ecotoxicity, 4.43 times higher on aquatic acidification and 13 times higher on damage category ecosystem quality. In addition, it has terrestrial ecotoxicity and chrome pretannage has marginally higher value of non-carcinogens. Comparing all impact and damage categories, Aluminum pretannage process has higher environmental burden than chrome pretannage process.*

Keywords: LCA, SimaPro software, functional unit and environmental impact.

1. INTRODUCTION

The new technology sets out to avoid the use of chromium salts, the alternative to wet blue is termed 'wet white'. Wet white can be produced in many ways, using tanning materials such as aluminium salts, aldehydes, syntans, zirconium (IV) salts, titanium salts. Among the many methods, aluminium pretannage received attention for the production of wet white leather in recent years and it was considered less toxic to ecosystem and human health [1]. The leather tanning process is composed of several batch stages associated with the consumption of large amounts of freshwater as well as the generation of liquid and solid wastes. The wastewaters are characterized by significant organic load and remarkably high concentrations of inorganic compounds such as chromium, chloride, ammonia, sulfide, and sulfate [2] [3]. Among these, tanning agents from chromium metal poses a challenge to the future sustainability of the leather industry with a growing number and layers of non-tariff barriers, including environmental considerations and eco-criteria emanating from major export markets. A useful tool to evaluate the environmental burdens associated with a product, process or activity is life cycle analysis or assessment (LCA). The objectives of this environmental management tool are the identification and quantification of the input and output flows of the process: energy and materials used and wastes released into the environment [4]. LCA techniques have emerged in the last 30 years and are now well established as an effective tool to measure the impact of a product or process on the environment in an effort to reduce the environmental burdens[5].The application of LCA in process selection, design, and optimization is gaining wider acceptance and methodological development[6][7][8]. The life cycle assessment framework consists of four phases. They are: goal definition and scoping, inventory analysis, impact assessment and improvement analysis. The definition of the scope of the LCA sets the borders of the assessment – what is included in the system and what detailed assessment methods are to be used [8]. The second step (inventory analysis) includes inventory of the inputs such as raw materials and energy and the outputs such as wastes and emissions that occur during the life cycle. The third step (impact assessment) is integration of inventory elements into an assessment of environmental performance which requires the emissions and material used to be transformed into estimates of environmental impacts. The results of this stage of LCA are termed as 'ecoprofile' [9]. The final step is interpretation of the results of impact assessment and suggestions for improvements[10].The leather industry in Bangladesh is considered as one with considerable growth and investment potential, ranked fifth in the export earning sector and covers 0.5% of the world's leather trade which is worth US$75 billion[11]. The European Community established an Eco label scheme, which is intended to promote the design, production, marketing, and use of products and services with reduced environmental impact [12]. These ecological criteria are described based on life cycle considerations. Eco label can promote the use of cleaner technologies in any sector that has been traditionally considered very polluting as that of leather industry. Leather products are on the list of priority products selected for Eco labeling [13]. The present study investigated the environmental impact of pretannage process using chromium salts against aluminium salts which is considered safer in terms of environmental standing. It will help to identify environmental burden and scope of improvement of the concern process.

2. GOAL AND SCOPE DEFINITION

The goal of this study is to determine and compare the environmental burden of the representative leather process pretannage using chromium salt and aluminum salt which will help to identify impact of different impact categories. Therefore, to find out where the environmental performance can be improved. Moreover it serves as a source of information for other tanneries or industries which may be interested to study the impact of their processes by applying the LCA methodology. Range of thickness of curst leather does not vary substantially from one article to the other. It was assumed based on in house observation. The functional unit chosen is 1 square meter leather. Therefore all the emissions are calculated in relation to the production of 1 square meter leather.

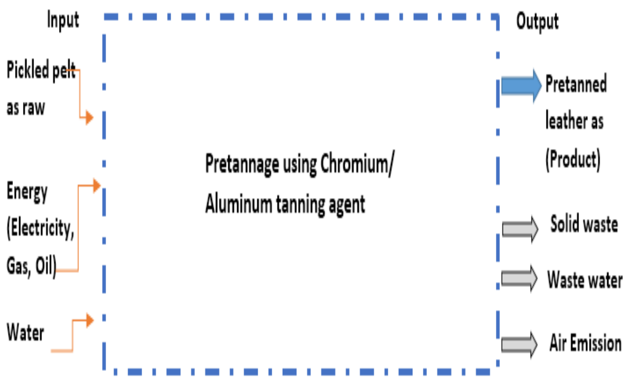

Fig.1: System boundary for pretannage process using aluminium and chromium salts

According to the detail system boundaries illustrated in Figure 1, it differs only in tanning agents. Other major upstream processes like slaughtering, preservation, presoaking, soaking, liming, deliming, bating and pickling are same for both leather. Chrome retanned leather follows pretannage using basic chromium sulfate tanning whereas wet white leather follows pretannage using basic aluminium sulfate. Pretannage is defined as incomplete and more or less superficial tannage of pelt with some special tanning agent before the main tannage in order to facilitate this. Data are based on Bangladeshi system that reasonably approximate this country's practices. All data used here are less than 10 years old to provide a reasonable approximation of current practices and energy systems. Data concerned to Pretannage of chrome retanned crust leather taken directly from production but pretannage using aluminium taken from laboratory trial. The proxy processes considered in this paper are transport for raw material, chemical and product delivery (from gate to Chittagong port); Electricity production country mix data taken from Malaysia since it resembles our production system; electricity generation using diesel generator and emission data of diesel fueled steam boiler. All these proxy processes data taken from SimaPro database libraries (Ecoinvent v3). Slaughtering data was sourced from Joseph and Nithya, 2009. But none of the proxy processes has been showed in the impact assessment since all most all are same for both system under consideration.

3. LIFE CYCLE INVENTORY

An analysis of the physical and chemical characterization of wastewater emissions of the leather processes was performed. The major tests conducted were chemical oxygen demand (COD), NH_3-N, NO_2-N, NO3-N, PO_4-P, total chromium. Data collection included annual wet-salted raw hides/skins consumption, input chemicals consumption, water and steam consumption, tannery solid waste generation, electricity, fuel oil consumption for generator and steam boiler but will not be showed in this study. Tests were conducted at Environmental Engineering laboratory, Dept. of Civil Engineering, Bangladesh University of Engineering and Technology (BUET). The samples being analyzed were waste liquor of presoaking, main soaking, liming, deliming and bating, pickling, pretannage (chrome retanned) and pretannage (chrome retanned). Table 1 shows the input and output of both pretannage systems and pretannage process recipe for both leather has been shown in table 2.

Table 1: Summary of inputs and outputs of pretannage process for both systems (1 m^2)

Parameters	Units	Pretannage	
		Aluminium	Chromium
Water	m3	0.0040	0.0025
Chemicals	Ton	4.02E-04	4.81E-04
COD	mg	70180	17380
NO3-N	mg	583	15
NO2-N	mg	Not measured	0.11
NH3-N	mg	6081	1367
PO4	mg	86	532
Total Cr/Al	mg	9149	5407
Cr+6	ppm	Not measured	0.06

Table 2: Comparative representation of recipe for pretannage using aluminium and chromium salts

Quantities in kg per m^2 of aluminium pretanned leather	Chemical used For aluminium pretanned leather	Quantities in kg per m^2 of chrome pretanned leather	Chemicals used for chrome pretanned leather
0.014	Alum	0.036	hypo
0.287	Novaltan AL	0.144	Basic chromium sulfate
0.287	Savintan	0.025	PEM
0.014	RWP		
0.050	Water	0.013	Bushan 30L
1.440	Basifying agent	0.018	Derugan Z
		0.144	RWP
		0.072	Tanigan OS
		0.065	Sodium Bi carbonate
		0.002	Bushan 30L pile up

4. IMPACT ASSESSMENT

The impact assessment was conducted based on impact 2002+methodology. SimaPro has been used to analyze and compare these two processes namely chrome pretannage for chrome retanned crust leather and aluminum pretannage [14]. This method links all types of LCI results via several midpoint categories like carcinogens, non-carcinogens, respiratory inorganics, respiratory organics, ionizing radiation, ozone layer depletion, aquatic ecotoxicity, terrestrial ecotoxicity, aquatic acidification, aquatic eutrophication, terrestrial acidification/nitrification, land occupation, global warming, non-renewable energy consumption and mineral extraction to four damage categories (human health, ecosystem quality, climate change and resources). Linking to midpoint is associated with certain conversion factors for each pollutant and conversion to damage categories is also associated with damage factors [15].

4.1 CHARACTERIZATION ASSESSMENT

Figure 2 shows the relative contribution to the following impact categories. Figure 3 shows the contribution to damage categories namely human health and ecosystem quality. According to figure 2 and 3, Kg equivalent of a reference substance expresses the amount of a reference substance that equals the impact of the considered pollutant (e.g. TEG-Triethylene glycol) in the midpoint categories. PDF•m^2•y (Potentially Disappeared Fraction of species disappeared on 1 m^2 of earth surface during one year) is the unit to measure the impacts on ecosystems. DALY (Disability-Adjusted Life Years) characterizes the disease severity, accounting for both mortality (years of life lost due to premature death) and morbidity (the time of life with lower quality due to an illness, e.g., at hospital) [15].

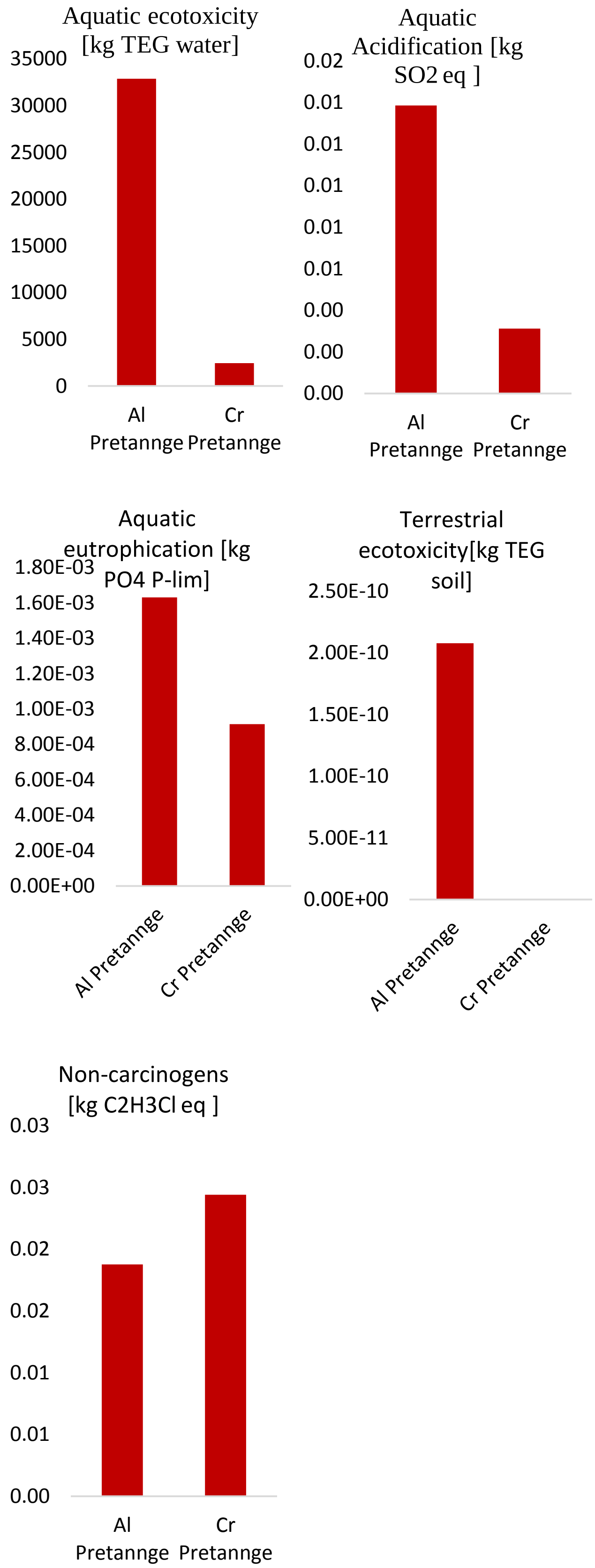

Fig.2: Impact assessment of both pretannage systems

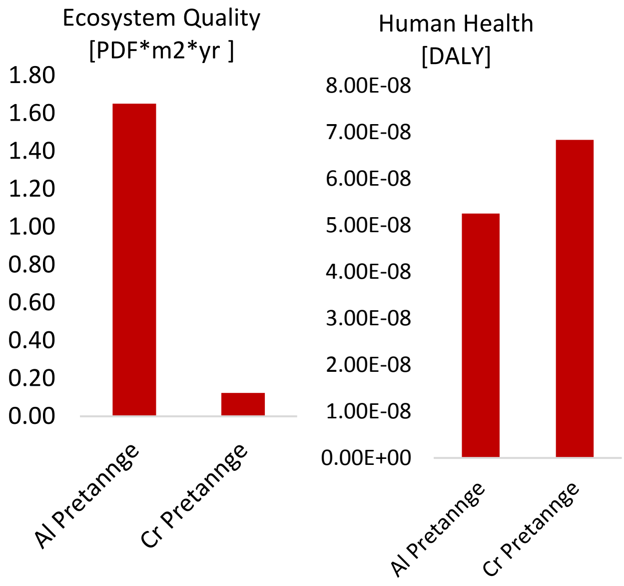

Fig.3: Damage assessment of both pretannage systems

I. Aquatic ecotoxicity

This category is dominated mostly by aluminium pretanned process and this process contributes more than 13 times higher. According to figure 3 (a), both processes contributed 32905 and 2451 kg TEG water respectively. The ecotoxicity of these processes mentioned above is due to the associated heavy metal emission into water.

II. Aquatic acidification

This category is dominated mostly by aluminium pretanned process and this process contributes more than 4 times higher. According to figure 3 (a), both processes contributed 1.39E-02 and 3.12E-03 kg SO_2 equivalent respectively. The aquatic acidification of these processes mentioned above is due to ammonia emission into air and water and ammonia as N.

III. Aquatic eutrophication

According to figure 3 (a), the amount of kg PO_4 P-lim emitted by the above processes are 1.63E-03 and 9.15E-04 respectively. Noticeably, aluminium pretanned process is about 2 times greater than chrome pretanned process. The aquatic eutrophication of these processes mentioned above is due to higher COD and PO4 discharge into water.

IV. Non-carcinogens

Chrome pretanned process contributed slightly higher compared to aluminium pretanned process which are 0.018 and 0.02 Kg C_2H_3Cl eq respectively. Non-carcinogens effect of these processes mentioned above is due to the associated heavy metal emission into water and ammonia release into air and water.

V. Terrestrial ecotoxicity

Terrestrial ecotoxicity category is completely dominated by aluminium pretanned process which is 2.07E-10 kg TEG soil. Release of pollutants such as aluminium, lead, zinc etc. into soil along with other pollutants mentioned in respiratory organics and inorganics into soil, air and water contribute to this category.

4.2 DAMAGE ASSESSMENT

All midpoint categories except aquatic acidification and aquatic eutrophication have been grouped into four damage categories namely climate change, human health, ecosystem quality and resources. These two midpoint categories are represented separately from the four damage categories.

I. Ecosystem quality

The damage category ecosystem quality is the sum of the midpoint categories aquatic ecotoxicity, terrestrial ecotoxicity, terrestrial acidification/nitrification and land occupation. According to figure 3, this category is strongly dominated by aluminium pretanned process which are 1.65 and 0.12 PDF*m^2*yr. respectively. This process contributes more than 13 times higher.

II. Human health

The human health category is the sum of the midpoint categories carcinogen and non-carcinogen, respiratory organics and inorganics, ionizing radiation, ozone layer depletion. This damage category is slightly dominated by chrome pretanned process. According to figure 3, the contribution of both processes are 5.25E-08 and 6.83E-08 DALY respectively.

5. SCOPE FOR IMPROVEMENTS

The remedial measures recommended under this study are mostly substitution of chemicals, simple technological change, process modification, and input chemical reduction. It is clearly indicated in the characterized values the company has serious impact on terrestrial ecotoxicity, aquatic ecotoxicity and aquatic acidification which results increased contribution to ecosystem quality damage category. Aquatic eutrophication and Non-carcinogen take the next position. Effluent treatment plant will significantly reduce environmental load of the following parameters. Chemical modification of chromium tanning salt can be one of the options for enhancing the uptake of chromium. Synthetic tanning material based on chromium improved significantly (90%) chromium uptake [16]. Enhancement of chromium uptake in tanning using oxazolidine and a decreasing of the chromium load in wastewater can be achieved [17]. Modification of process such as reduction of float is another tool for improving the chromium uptake. Carrying out chrome tanning without float and increasing the temperature at the end of the tanning process brought about 91% reduction in chromium discharged [16]. Recently CO_2 proposed as process additive for free of water tanning [18]. The main contributor to this category are chromium (III), chromium (VI) and ammonia. Solutions to these emissions are discussed under eutrophication and non-carcinogens categories.

6. CONCLUSION

In this study, major emissions considered by Impact 2002+ method were heavy metal chromium and aluminium discharge into water, high COD and ammonia as N wastes produced in pretannage process. These emissions are responsible for the contribution of the concern process to significant toxicological impacts namely aquatic ecotoxicity, terrestrial ecotoxicity, aquatic acidification, aquatic eutrophication and non-carcinogens which eventually contributed to damage categories human health and ecosystem quality. The main contributor for chrome pretanned leather's environmental impact are non-carcinogens, aquatic ecotoxicity, eutrophication and acidification. Solid wastes generated from different stages of production were merely identified and quantified but corresponding emissions and subsequent impact have not been analyzed and assessed.

7. REFERENCES

[1] A. D. Covington and T. Covington, Tanning Chemistry: The Science of Leather. Royal Society of Chemistry, 2009.

[2] O. Tünay, "Characterization and pollution profile of leather tanning industry in Turkey", Water Sci. Technol., vol. 32, no. 12, pp. 1–9, 1995.

[3] E. Ates, D. Orhon and. Tunay, "Characterization of tannery wastewaters for pretreatment-Selected case studies", Water Sci. Technol., vol. 36, no. 2–3, pp. 217–223, 1997.

[4] F. Consoli, D. Allen, I. Boustead, J. Fava, W. Franklin, A. Jensen and N. De Oude, "Guidelines for Life-Cycle Assessment: A "Code of Practice." Society of Environmental Toxicology and Chemistry (SETAC), 1993.

[5] C. Jiménez-González and M. Overcash, "Energy sub-modules applied in life-cycle inventory of processes", Clean Prod. Process, vol. 2, no. 1, pp. 57–66, May 2000.

[6] R. Clift, "Overview Clean Technology—the Idea and the Practice", J. Chem. Technol. Biotechnol., vol. 68, no. 4, pp. 347–350, Apr. 1997.

[7] R. Clift, "Engineering for the environment: the new model engineer and her role", Process Saf. Environ. Prot., vol. 76, no. B 2, pp. 151–160, 1998.

[8] A. Azapagic, "Life cycle assessment and its application to process selection, design and optimization", Chem. Eng. J., vol. 73, no. 1, pp. 1–21, 1999.

[9] K. Joseph and N. Nithya, "Material flows in the life cycle of leather", J. Clean. Prod., vol. 17, no. 7, pp. 676–682, 2009.

[10] D. T. Allen and D. Shonnard, Green Engineering: Environmentally Conscious Design of Chemical Processes. Prentice Hall PTR, 2002.

[11] H. L. Paul, A. P. M. Antunes, A. D. Covington, P. Evans, and P. S. Phillips, "Bangladeshi Leather Industry: An Overview of Recent Sustainable Developments", J. Soc. Leather Technol. Chem., vol. 97, no. 1, pp. 25–32, 2013.

[12] EU, "Regulation (EC) No 1980/2000 of the European Parliament and of the Council of 17 July 2000 on a revised Community eco-label award scheme," 2000.

[13] B. Rivela, M. T. Moreira, C. Bornhardt, R. Méndez, and G. Feijoo, "Life cycle assessment as a tool for the environmental improvement of the tannery industry in developing countries", Environ. Sci. Technol., vol. 38, no. 6, pp. 1901–1909, 2004.

[14] PRé, "Introduction to LCA with SimaPro," 2013.

[15] S. Humbert, M. Margni, and O. Jolliet, "IMPACT 2002+: User Guide Draft for version 2.1", Switzerland, 2011.

[16] G. Lofrano, S. Meriç, G. E. Zengin, and D. Orhon, "Chemical and biological treatment technologies for leather tannery chemicals and wastewaters: A review", Science of the Total Environment, vol. 461–462. pp. 265–281, 2013.

[17] S. Sundarapandiyan, P. E. Brutto, G. Siddhartha, R. Ramesh, B. Ramanaiah, P. Saravanan, and A. B. Mandal, "Enhancement of chromium uptake in tanning using oxazolidine", J. Hazard. Mater. vol. 190, no. 1–3, pp. 802–809, 2011.

[18] R. Manfred, W. Eckhard, J. Björn, and G. Helmut, "Free of water tanning using CO2 as process additive—an overview on the process development", J. Supercrit. Fluids, vol. 66, pp. 291–296, 2012.