

Bioremediation of Tannery Effluents for Sustainable Production of Leather in Uganda: Literature Review

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Abstract

Tannery industry in Uganda has to comply with both local and international environmental standards if it is to remain sustainable. Failure to comply with the local and international environmental standards, this industry will have three fates in the country: first, hides and skins will either be half processed or exported in raw form; second, tannery waste effluents will escape to the environment beyond permissible levels, posing a risk to aquatic life and human health and safety in the country; third, exporting raw hides and skins due to fear of the closure of full operation as they fail to meet compliance requirements for the tannery effluents in the country. This results into donating jobs and other products of hides and skins. We propose the in-depth study of the suitability of bioremediation technology as a possible sustainable treatment technology for tannery effluents which unfortunately is not properly documented in the country. Bioremediation of tannery effluents method has fully been documented by 5,800 researchers as shown in the google scholar search engine, indicating that it serves as a better method for treatment of tannery waste because of being environmentally friendly.

Keywords: Tannery industry; Bioremediation technology; Human health and safety; Hides and skins

Introduction

Bioremediation process

Bioremediation process has been applied worldwide using active microbes to manage terrestrial and aquatic ecosystems said by Ang et al., Dua et al. and Gavrilescu [1-3]. It was also asserted that, bioremediation uses biological process to overcome environmental problems like treating waste or pollutants by the use of microorganisms (as bacteria) that can break down the undesirable substances [4]. Alexander [5] further said that bioremediation relies largely on the enzymatic activities of living organisms, usually microbes, to catalyze the destruction of pollutants and transformation of pollutants to less harmful forms. Then Das and Chandran [6] stressed that it is a complex process depending on many factors including ambient environmental conditions (such as pH, Temperature, nutrients and molecular oxygen), Composition of the microbial community and the nature and amount of pollution present. McCullough et al. [7] said among the microbial communities (organisms) that have been tested and proved as successful bioremediators include algae, protozoa, bacteria, archaea and fungi. However, bacteria has been found to be the most successful bioremediator due to their mode of reproduction and nutrition [8]. This build the foundation of the work undertaken in this research because it is intended to use bacteria as the active microorganisms for bioremediation of tannery waste. The advantage of using bioremediators to restore the environment is that the ecosystem is left with metabolites that are environmentally friendly [9]. Most of the

metabolites left are usually biodegradable [10]. Microorganisms are so important in this process because they have extraordinary metabolic diversity [11]. Bioremediation has proved a better option in cleanups. For instance, natural attenuation that involves dispersion, biodegradation, irreversible sorption, and/or radioactive decay of contaminants in soils and ground waters has been made possible. Studies have showed that it causes a net reduction of contaminant toxicity, human and ecological risk. Despite the above advantages, environmental remediation has rarely been taken advantage of especially in tropics [12]. Furthermore, bioventing process has shown in a recent study by Hoeppel et al. [13], that it has a potential of stimulating the natural *in situ* biodegradation of contaminants in soil by providing air or oxygen to existing soil microorganisms. The study further added that it has been found out to be using low air flow rates to provide only enough oxygen to sustain microbial activity in the vadose zone. Another study by Benner et al. [14] showed that air sparging also known as *in situ* air stripping and *in situ* volatilization is an *in situ* remediation technique. It is used for the treatment of saturated soils and groundwater contaminated by volatile organic compounds (VOCs) like petroleum hydrocarbons which is a widespread problem for the ground water and soil health. Das and Chandran [6], showed that biostimulation that is to say, the addition of nutrients rich in nitrogen and phosphorus to a contaminated environment can stimulate microorganisms capable of biodegradation of the pollutants such as oil. Several developed countries have been noticeable to be using bioremediation for treatment of waste water. For example North America by Corseuil and Alvarez [15], Pakistan by Malik et al. [16] and China by Zhou et al. [17] have demonstrated bioremediation potential to clean up water containing heavy metals and organic pollutants. In North America, bioremediation has been

used to clean up Canada's DEW line sties in the arctic and has been used to clean up after oil spills off of Alaska [18].

Measuring extent of bioremediation

In several studies for example Tang et al. [19], McCullough et al. [7] and Kasiri et al. [20] that have been done on bioremediation, physiochemical parameters have been measured using spectrophotometry or chromatographic techniques with Mwinyihija et al. [21] emphasizing the use of biosensors. Bio-sensor is a sensor that integrates a biological element with a physiochemical transducer to produce an electronic signal proportional to a single analyte which is then conveyed to a detector [22]. Typical Sensing Techniques for Biosensors include Fluorescence, DNA Microarray, SPR Surface Plasmon resonance, Impedance spectroscopy' SPM (Scanning probe microscopy, AFM, STM), QCM (Quartz crystal microbalance), SERS (Surface Enhanced Raman Spectroscopy) and Electrochemical techniques [22,23]. In the studies [22,24] biosensors were used and found to be successful at quantifying the physio-chemical parameters. Besides, biosensors are found to be portable, easy to manage with less training, faster at reading results and less costly. In addition, biosensors use portable batteries instead of power lines. These features make them suitable in the tropical setting where people are not very trained to operate sophisticated equipment. Also, the tropical setting is characterized with high load shading (power fluctuations). In fact, most of the bioremediation is done in rural settings with no power lines to support the spectrophotometry and chromatographic methods which are commonly used in the analysis. Biosensors can be fitted into the system as chips to give online processing readings as water flows in the treatment system enabling immediate action [25]. With this feature, it can be incorporated into the automated self-check system for easy effluent management from water treatment plants [26]. This would improve on the healthy sea food production if the effluent to lakes and rivers is made suitable to enter the aquatic environment. Although, biosensors are ought to have all the above advantages, no comparison has been made on the efficiency of the three methods in Uganda. This will be the focus of the current study.

Effluents from tanneries

Water, wetting agents, enzymes, lime, sulphide, Na₂S, ammonium sulphate, (NH₄)₂SO₄, sodium chloride, NaCl, sulphuric acid, H₂SO₄, chromium sulphate Cr₂(SO₄)₃ and sodium bicarbonate, NaHCO₃ as well as pre-tanning chemicals like fat liquors and dyes are the most common inputs of tanneries as in the study by Amarnath and Krishnamoorthy [27] and summarized in the Figure 1 below.

The flow chart in Figure 1 shows the inputs of a leather tanning process and the associated wastes that can be either liquid waste or solid wastes. Liquid waste affects the following water parameters:

BOD5, COD, Total organic compounds, Azo-dyes, Chromium (III), Chromium (VI), sulphide (S₂⁻), Cadmium, Lead, Mercury and TDS while the solid waste does affect basically suspended solids accumulation.

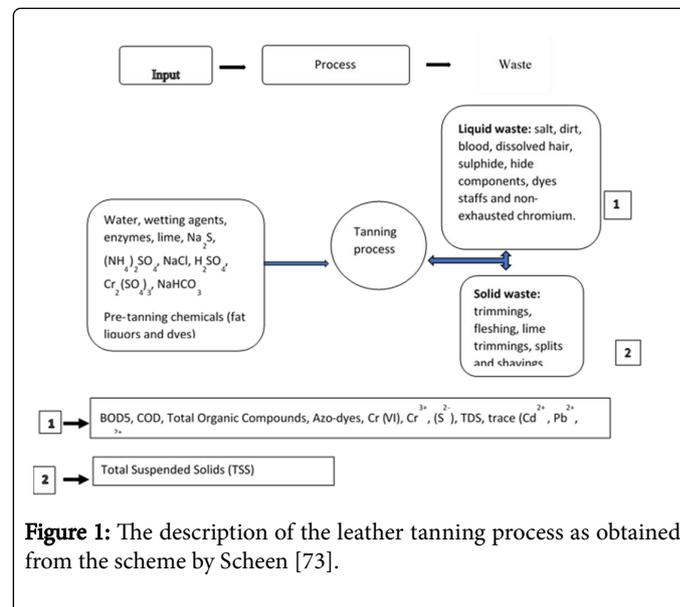


Figure 1: The description of the leather tanning process as obtained from the scheme by Scheen [73].

It has been asserted by Sreeram and Ramasami [28] that the consumption of chromium during tanning process under optimal conditions of tanning is of the order of 40–70% of chromium that was added. This would mean 30–60% of chromium can be lost as waste to the surroundings after any tanning operation as described by Kolomaznik et al. [29]. If the effluents are released to the environment with incomplete treatment, the amount of trivalent chromium may increase enormously within a year. This can be oxidized to hexavalent chromium by oxidizing agents to cause the contamination of soils and water, hence posing risk to human health and safety. Wastes are usually discharged into the environment with incomplete treatment. Thus, polluting aquatic and terrestrial ecosystems plus the atmosphere, making leather production unsustainable [30]. To solve this, an environmentally friendly method is needed i.e., bioremediation.

Characteristics of effluents

Nacheva et al. [31] asserted that all the stages of the 10 steps of the tanning process as in Table 1 are capable of producing enormous effluents that affect a vast number of environmental parameters. These parameters have an effect on the quality of water for drinking, soil for agriculture and air for breathing.

Parameter	Process effluents								
	soak	liming	de-liming	pickling	Cr tanning	Tannins tanning	Re-tanning	Fat liquoring	Dyeing
pH	7.5	12.9	8.2	2.4	4.3	4.9	4.68	4.9	4.28
TSS, mg/l	6955	25310	1613	1315	1200	9350	960	675	521
COD, mg/l	9266	29600	8800	7620	11400	38570	5151	7587	8033

BOD ₅ , mg/l	7920	10780	4200	3880	5700	12970	2230	2517	3607
O & G, mg/l	243	828	199	148	412	480	0	114	200
S ₂ ⁻ , mg/l	5	3660*	430	2	30	0	171	149	141
k, mS/cm	64.3	32.9	27.2	79.4	77.1	76.7	11.0	8.7	9.0
TKN, mg/l	380	2730	2205	1108	820	1266	510	275	220
NH ₄ -N, mg/l	174	742	1210	947	719	940	255	140	189
Cr ₃ ⁺ , mg/l	0	0	0	0	4500	0	50	1	1

Table 1: Characteristics of effluents in bovine tanneries with the complete manufacturing process as reported by Nacheva et al. [31]. *When hair-burn method is used. The average obtained for hair-save spent liquors was 1860 mg/l.

Rationale

Leather tanning steps

Leather tanning process involves about ten steps as identified from Tunay et al. [32], on the study of the use and minimization of water in leather tanning processes and Thanikaivelan et al. [33] on the progress and recent trends in biotechnological methods for leather processing, this can be seen in Table 1 above. Each step uses a number of chemicals which are also released in effluents as depicted by Porter and Van der Linde [34] on their study on the trend towards a new conception of the environment-competitiveness relationship. The effluents can be in liquid and solid state in any tannery operation as it was said by Hu et al. [35] and Fathima et al. [36].

Emphasis of other researchers

In Uganda researchers have been putting much emphasis on numbers of tannery industries and not paying much attention to the quality of their effluents as said by Temsch and Marchich [37] in the UNIDO report on the strengthen the leather sector in Uganda project. For instance, it was reported that our Uganda has seven large tanneries and two small ones with installed capacity to process close to 10,000 hides and 47,000 skins per day as was reported in the newspaper entitled the daily monitor- Uganda on Dec 7, 2016. On the other hand, there isn't any research focusing on the treatment of tannery effluents from these factories and tracing their danger to communities. On interviewing district residents, it was found out that some large-scale tanneries have a well-constructed effluent treatment plant but on the other hand others just release the effluents to the nearby swamp as reported by local residents. This gives a view that could be the source a serious stench in the villages along the wetland next to the tanneries.

Affected areas and their level of awareness

Locals in the areas affected include Ngendo-Masaka and those along the swamp and on a sad note some interviewed locals appeared not to know the cause of stench in the area and the operators of the tannery appear not to be concerned with the effects of the chemicals disposed to the swamp on the residents. On a surprise note, no researcher has picked courage to find out how much of the pollutants in the effluents are present in this wet land which is a water source of the locals in the area. On the other hand, Jinja has five large scale tanneries of which those near Jinja municipality are also producing stench as reported by the residents interviewed from there and similarly no research is being

conducted to follow the source and the effect of the stench. These concerns from local residents suggest a possibility of some of the tanneries to be operating without properly constructed effluent treatment plants.

Risk of tannery effluents

The fear is that people will continue to be exposed to the tannery effluents which posed a risk to human health and safety [38] that may lead to various infections in the country as stated by Wabinga et al. [39] and Wabinga et al. [40]. For this reason, the focus is to assess the suitability of bioremediation as a potential sustainable treatment technology for tannery effluents [41] and provide a solution to the affected tanneries in order to save the environment and residents at large. The point of contention is to carry out the baseline study on tannery effluents treatment status in Uganda in the same way as describe in Ali et al. [42] more still to characterize and determine physical chemical composition of tannery effluents as depicted in the study by Cooman et al. [43], further to devise culturing bacteria for bioremediation of the selected tannery pollutants following Tripathi et al. [44] and also identification of selectable marker for bacteria capable of bioremediation of heavy metals following Pieper and Reineke [45] method at the tannery sites. Conditions at the local site may not favour bioremediation active bacterial, therefore carrying out bioremediation at varying selected physical-chemical conditions as described by Noorjahan [46] and optimizing the synergic effect of the combined cultured bioremediation active bacteria to treat the selected pollutants in the tannery effluent in accordance with Verma and Singh [47].

Noticeable bioremediation studies

Researchers in several developed countries have been noticeable on bioremediation studies for treatment of tannery effluents. For example North America [15], Pakistan [16] and China [17] have carried out intensive research on bioremediation potential to clean up heavy metals and organic pollutants from tanneries before reaching the environment. Since the studies overseas have shown that it works, it can work also in Uganda.

To save Ugandans we need to research on both the numbers of tanneries producing leather and also on their ability to treat their effluents in order to keep the environment clean from tannery pollutants. The current work is addressing the treatment of tannery effluents option to make leather production in Uganda sustainable and marketable both nationally and internationally.

Methods

Literature search strategy

Relevant literature was selected from PubMed and google scholar because of their multidisciplinary nature of being used by researchers in the world while EndNote was selected to arrange the citations, references and bibliography.

Science Citation Index was also used, the database allows a researcher to identify which later articles have cited any particular earlier article, or have cited the articles of any particular author, or have been cited most frequently

Endnote x7 was also adapted to fit citations into our text in this work. EndNote is a commercial reference management software package, used to manage bibliographies and references when writing essays and articles.

Selection of articles for review

Relevant studies were searched from PubMed and we were able to identify 135 articles all reflecting tannery effluent treatments methods. Unfortunately, none on PubMed reflected bioremediation of tannery effluent treatment technology method. On the other hand, google scholar reflected 5,100 articles with bioremediation technology as a

possible method of treating tannery effluents. Neither PubMed nor google scholar reflected bioremediation technology as a method to treat tannery effluents in Uganda.

Results

Our literature review from PubMed and google scholar articles identified several provisions and mechanisms on which bioremediation of tannery effluents treatment is based. These mechanisms included Carrying out a baseline study on tannery effluents treatment status in Uganda; characterizing and determining physical chemical composition of tannery effluents; culturing bacteria for bioremediation of the selected tannery pollutants and Identification of selectable marker for bacteria capable of bioremediation of heavy metals at the study sites; carrying out bioremediation at varying selected physical-chemical conditions and optimizing the synergic effect of the combined cultured bioremediation active bacteria to treat the selected pollutants in the tannery effluent.

Selected literature also reflected that, Uganda has 7 large scale tanneries [48] which if not managed properly could pose a risk to Lake Victoria and hence on River Nile. The tanneries are indicated in the Table 2 below.

Name	Products	Location of industry
Uganda Leather Industries Ltd, Jinja	Wet blue and finished leather	Jinja district
Sky Fat Tannery Co. Ltd (SFT)	Wet Blue Hides and Wet Blue Skins	Jinja district
Novelty Investment Tannery Ltd	Wet blue and Hides/skins	Masaka district
Uganda Fish Leather Tannery Ltd, Jinja	Crust and finished skin from Nile Perch	Jinja district
Balawi Hides and Skins	Wet blue and Hides/skins	Busia District
SWT Tanners Ltd.	Wet blue and Hides/skins	Jinja District
Elgon Leather U Ltd	Wet blue and Hides/skins	Masaka district

Table 2: Tanneries in Uganda. Source: National Association of Professional Environmentalists (NAPE)-Uganda.

Carrying out a baseline study on tannery effluents treatment status in Uganda

Locals of the affected areas in Jinja and Masaka revealed that community knowledge about the tannery effluents in districts is very low but perception of tannery benefits is at large. In addition, resident's knowledge about monitoring and specifically, community-based monitoring is very low as well as knowledge about implementers and donors, including who they perceive to be responsible for monitoring projects. We propose to carry out a baseline study on tannery effluents treatment status in the two most affected districts in the country, that is, Masaka and Jinja.

Characterizing and determining physical chemical composition of tannery effluents

It was revealed in the study by Gandini [49] that leather processing uses renewable resources for this reason it should provide a sustainable

yield (the rate of harvest should not exceed the rate of regeneration). It was further stressed by Patel et al. [50] that there should be equivalent development of renewable substitutes for non-renewable resources to counteract environmental stress. The study by Islam et al. [51] suggested that the waste generation should not exceed the assimilative capacity of the environment. Kneese et al. [52] on the study of tannery effluents management stated that sustainable development primarily calls for renewable raw materials (controlled levels of chemicals), reduction and recycling of waste. It was reported by Kalyanaraman et al. [53] on tannery treatment study that controlling the limits of BOD5, COD, Total organic compounds, Azo-dyes, suspended solids, chromium(III), Cr_3^+ , chromium(VI), Cr_6^+ , sulphide, S_2^- , Cadmium, Lead, Mercury and total dissolved solids, TDS to recommended levels makes the tanning process sustainable. It was also stressed by Batzias et al. [54] on the study of tannery treatment methods that, BOD5, COD, Suspended Solids, Cr_3^+ , S_2^- , TDS are the most important parameters to control when disposing the effluents to the environment. It was reported by Leta et al. [55] that BOD5 and COD levels in tannery

effluents can be controlled with bioremediation techniques using microorganisms without affecting the environment. A study on the control of organic substances in tannery effluents revealed that Total organic compounds, can also be best controlled by the bioremediation techniques while preserving the environment [56].

Culturing bacteria for bioremediation of the selected tannery pollutants and identification of selectable marker for bacteria capable of bioremediation of heavy metals at the study sites

Bacteria of the type *Pseudomonas aeruginosa* were found to have activity with hydrocarbons in the study by Kiraye et al. [57] and also can use carbon from other organic compounds as their energy source [58]. Other species of *Pseudomonas* family like *Pseudomonas fluorescens*, *Pseudomonas ambigua*, *Enterobacter cloacae* and *Bacillus subtilis* were reported to have the ability to convert chromium (VI) to chromium (II) [59]. It was reported that Cadmium can be used by bacteria thereby reducing it in the environment [60] the case in place being *Rhodobacter sphaeroides*. It was further found out by Abbas et al. [61] on the isolation, Identification, and Characterization of Cadmium Resistant *Pseudomonas* sp. study that, *Pseudomonas* sp. can remove almost 70% of cadmium from samples in their log-phase and this is affected by temperature and pH of the surroundings. Lead [62] asserted that Lead (Pb) is among the most largely existing heavy and toxic metals in the environment. It was also pointed out by further explained in his study that, utilization of lead resistant bacteria to remove this toxic metal could be exploited in the lead bioremediation method. Arsenic from the effluents can be effected by processes that favour simultaneous removal of iron [63] and on comparing what Cavalca et al. [64] did on the study of arsenic remediation, it was revealed that Rhizobacterial community can do the work. It was further reported in the study of mercury bioremediation that, *Pseudomonas putida* has the ability to reduce divalent mercury sulphides to Mercury metal, in this way mercury ions as well as sulphides can be bioremediated using these bacteria species [65]. Gremion et al. [66] on his analytical study on soil bacterial communities using 16S rRNA clone libraries revealed that actinobacteria might be a dominant part of the metabolically active bacteria in heavy metal remediation. Furthermore, Nogales et al. [67] with a study on Combined use of 16S ribosomal DNA and 16S rRNA to study the bacterial community of polychlorinated biphenyl-polluted soil also pointed out that Actinobacteria might be a dominant part of the metabolically active bacteria in dealing with heavy metal remediation.

Carrying out bioremediation at varying selected physical-chemical conditions

A study on *in-situ* bioremediation of organic pollutants asserted that treating waste or pollutants by the use of microorganisms that can break down the undesirable substances need specific physical-chemical conditions [68]. According to Oller et al. [69], the specific physical chemical conditions of the tannery effluents at the point of disposal would be the most ideal as the microbial load for the study is used to the local conditions of the area. Furthermore, Saxena and Bharagava [70] on the study of similar context showed that using the microorganisms of the area achieves better results if they happen to be bioengineered for bioremediation of the tannery effluents. These studies are in line with the overall focus of this study.

Optimizing the synergic effect of the combined cultured bioremediation active bacteria to treat the selected pollutants in the tannery effluent

The author was reported by Popp et al. [71] on the study entitled Bacterial diversity in the active stage of a bioremediation system that, combined effect of cultured bioremediation active bacteria show a good degradation power of effluent pollutants. Shah [72] on optimization of parameters in a tannery effluent treatment plants also asserted that, it is laborious to optimize new strains of bacteria to perform bioremediation of these effluents than to use dominant microorganism that have already colonized the area. This is in agreement with the current study, because the focus is to isolate the dominant bacteria which will later be transformed by plasmid insertion carrying bioremediation trait and reintroducing them back to the site to do the job.

Comments

The status of the country in as far as tannery effluents is concerned needs to be deeply explained in order to maintain the environmental cleanliness. The levels of contamination of Masaka wetland and lake Victorian needs to be studied as these are sources of food and water for the residents. Failure to have information on how much pollution tanneries have contributed to these resources might continue to increase the unexplained occurrences of unclear illnesses to people hence creating sick communities that may fail to be productive to the country. In addition, the areas affected in central Uganda serve as food baskets of the region. Polluting soils and water of this area will have a pronounced effect on the agricultural and horticultural activities hence jeopardizing food security of the region as it is noticed in some parts of these villages.

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