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Enginyeria en Tecnologies Industrials

Assessment of tannery solid waste management

A case of Sheba Leather Industry in Wukro (Ethiopia)

REPORT

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Summary

This cooperation project was born with the motivation of helping and proposing solutions for a real environmental problem in a developing country that do not have easy access to facilities and services. The main objective of the project is based on analysing the solid wastes generated by a tannery named Sheba Leather Industry from Wukro, Ethiopia, in order to suggest appropriate solid waste management practices. The project studies the possibility of implementing the composting method as a solution to treat part of the waste.

Ethiopia is well known for its largest livestock population. The production of leather from skins and hides is one of the leading industrial sectors in the country. The tanning industry is one of the most polluting industries generating large quantities of solid wastes and creating negative environmental impacts. Aiming to approach this problem, in this study, assessment on solid waste management practices and characterization of the solid wastes generated by Sheba Leather Industry were carried out so that suitable tannery solid waste management solutions could be proposed.

The different operations performed during the leather manufacturing were examined and it was found that the company generates a total of 5,190 tonnes of solid waste every year. These wastes were physicochemically characterized. At that moment, the overall solid wastes generated are disposed to an open dumping area on the surrounding of the industry without receiving any previous treatment and, therefore, the surrounding area is being polluted.

Consequently, it was suggested the possibility of composting the non-containing chrome wastes such as hair, fleshings and trimmings with other organic matter in order to obtain a soil fertilizer that could be used to improve the quality of the damaged soils. One sampling was conducted showing that the decomposition of the raw materials occurred conveniently. However, the hair waste showed difficulties to decompose, and the company carried out a second sampling excluding that waste.
In order to perform this study, it was necessary to travel to Wukro, Ethiopia, and work on site. The research entailed 5,584.55 €.

The possibility of composting with the sludge, a hazardous solid waste containing chrome from the wastewater treatment, has been also theoretically studied. It is feasible to use this technology in order to reduce significantly the volume of the waste and improve its quality before disposing it in a secure landfill.

In addition, a composting plant capable of treating the free of chrome tannery wastes generated was designed and described. It occupies a total area of 2,500 m^2 and includes a reception/mixing unit, a piles unit, a deposit for leachate collection, and a site office. The idea is based on a unique pile of great dimensions (90.21 m of length x 18 m of width x 3 m of height) that needs to be periodically turned and water. The dimensions were determined considering that the plant receives 72 tonnes of waste every three days.

The composting plant will give work to three operators and the economic study has shown the necessity of a financial aid of 25,500 € every year to assure its continuity.

This proposal has been considered as an environmental friendly solution to deal with part of the waste and obtain a benefit from it. Further research is recommended in order to propose more solutions and avoid the adverse consequences of disposing waste without treating it previously.

INDEX

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1. Introduction

1.1. Motivations of the Project

This project begins after travelling to Wukro, a small town in the north of Ethiopia, in order to find a problem to be solved. After being aware of the current situation and becoming more familiar with their people, their culture and with their way of life, a research in order to study a problem in one factory of this region was proposed.

This factory, named Sheba Leather Industry, is a tannery in which different kinds of animal's hides and skins are processed with the aim of obtaining leather. The study will be focused on analysing the current status of the processes carried out in the industry as well as examining the amount of wastes produced. Subsequently, improvements of waste treatment practices will be suggested.

Wukro is a small city that is growing fast in the last few years and this factory that gives job to more than 760 Ethiopian employers is an example of it. However, no one will discuss the fact that the management of wastes in developing countries represents a serious problem that needs to be proximately solved. Especially, the Leather Industry has been categorized as one of the highly polluting industries causing negative impact on the environment.

This fact intensifies the motivation needed to start working on this project aiming to reduce as much as possible the big differences existing between developing and developed countries. Therefore, different solutions and proposals will try to be facilitated and suggested to these regions with lack of resources and awareness of environmental sustainability.

1.2. Scope of the Study

This study analyses the actual processes performed in Sheba Leather Industry in order to propose tannery solid waste management practices. Therefore, it will be essential to determinate the rate of the solid waste generated, to sample and characterize (physicochemical analysis) these solid wastes and to propose proper solid waste management options mainly focusing on composting.

The main aim of this study consists in gathering accurate and useful data of the nature and amount of solid waste generated during leather making operation from raw hides and skins input to finished leather. This necessary data is used to make an assessment of solid waste management facilities.

To achieve these goals, a three-months stay in Wukro (Ethiopia) was performed. This enabled to have a first hand experience and also facilitated the development of the project. The execution of this project has been possible thanks to the active support of the NGO Holystic ProAfrica. This familiar organization settled in Madrid, focuses on children physiotherapy issues. Although its typical projects are not related with engineering, they did not hesitate and have facilitated the contacts of the Ethiopian company and further information essential for starting this study. Without their help this project could not have been performed.

2. Objectives

2.1. General Objective

The general objective of this study is to quantify and characterized the solid wastes generated by Sheba Leather Industry in order to evaluate and propose suitable solid waste management practices.

2.2. Specific Objectives

The specific objectives of this study include:

- Understand and define the overall procedures performed during the leather production
- Knowledge of the existing solid wastes management systems used in Sheba Leather Industry
- Research of the practices carried out in leather industries
- Quantify the rate of solid wastes generated by the company in each operation
- Analysis and characterization of their solid wastes
- Segregate solid wastes depending on their nature and, subsequently, propose appropriate solid waste treatments
- Evaluate the feasibility of composting with some of the solid wastes by making and controlling different samples
- Propose a solid waste management practice for the sludge, a hazardous solid waste containing chrome
- Make a basic design and dimension of a composting plant capable of treating the selected wastes
- Study of the environmental impact that has the performance of the project as well as the operation of the composting plant
- Study of the economic investment and budget necessary in order to achieve the proposals of the research and, moreover, in order to make operational the composting plant

3. Background

3.1. Ethiopian Leather Industries

The leather making operation is conducted in a tannery and consists on converting the raw skin or hide, which is a highly putrescible material, into leather, a stable material that can be used in the manufacture of a wide range of products. The whole process consists in a sequence of complex chemical and mechanical processes. Amongst them, the fundamental stage is tanning. During this process the leather acquires stability and its essential character. By following all the steps, the initial raw hides and skins evolved into a final product with specific properties: stability, temperature resistance, elasticity and permeability for perspiration and air, appearance, water resistance, etc [1].

One of the leading industrial sectors in Ethiopia since ancient times is the production of leather from raw skins and hides [2]. In this country, strong and quality raw material base is provided for the leather industry. Ethiopia possesses the largest livestock population in Africa and the 10^{th} largest in the world [3]. Its livestock population is estimated at 53 million cattle, 24 million goats and 25 million sheep. Livestock are predominantly owned by smallholder farmers and pastoralists. The annual skin removal rate is nearly 10% for cattle, 38% for goats and 33% for sheep, (CSA, 2013). Considering the previous data, the Ethiopian government defines the leather industry as one of the priority sectors in the manufacturing industry. Finished leather and leather products are among the principal manufacturing export products positioning the leather industry as the leading exporter. In 2014, 105.9 million euros were generated by leather sector in Ethiopia [4].

The Ethiopian leather industry has gained momentum of growth over the last several years. The number of tanning industries that were handful ten years ago have now rose to 29 with more under formation [3]. The location and capacity of each leather company are listed in the *Annex A* and can be summarized in a soaking capacity of 1.3 million pieces of hide and 32 million pieces of skins per year which means 10,325 pieces of hide and 179,650 pieces of skins per day. Most of them are located in Addis Ababa and its surroundings [5].

Leather industry has been considered as one of the highly polluting industries and in Ethiopia the awareness on the harmful impact that leather-making activity can have on the environment is starting to raise. The large production of leather presents a considerable challenge to the industry taking into account the adverse nature of most of the chemicals used during the process. A huge amount of liquid and solid wastes are generated as long as gases such as H_2S, NH_3 and CO_2. Also obnoxious smell is emitted because of a degradation of proteinous material of skin. Therefore, all of these wastes need to be analysed and treated. The tannery solids wastes contain different chemicals according to the distinct mechanical and chemical processes applied to the hides and skins. They are mainly shacked salt, raw trimmings, hair waste, fleshings, splitting waste, chrome shavings and buffing dusts. An accumulation or a non-properly disposal of them might cause environmental problems.

Shacked salt, used to preserve hides or skins thrown into open dumping areas or accumulated in piles outside the tanneries, is likely to create groundwater pollution when rain washes it away. Hair waste and lime sludge discharged into the effluent can produce choking of treatment pipes. Trimmings, fleshings and splitting waste putrefy easily producing noxious odours. Chrome tanned shavings hardly discompose [6].

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Chromium salt is commonly used in tanning industries producing solid wastes containing chromium metal. This metal causes carcinogenic effect when entering human body through food chain [7].

In *Figure 3.1* below a simplified inflow and outflow of tanning industry is shown.

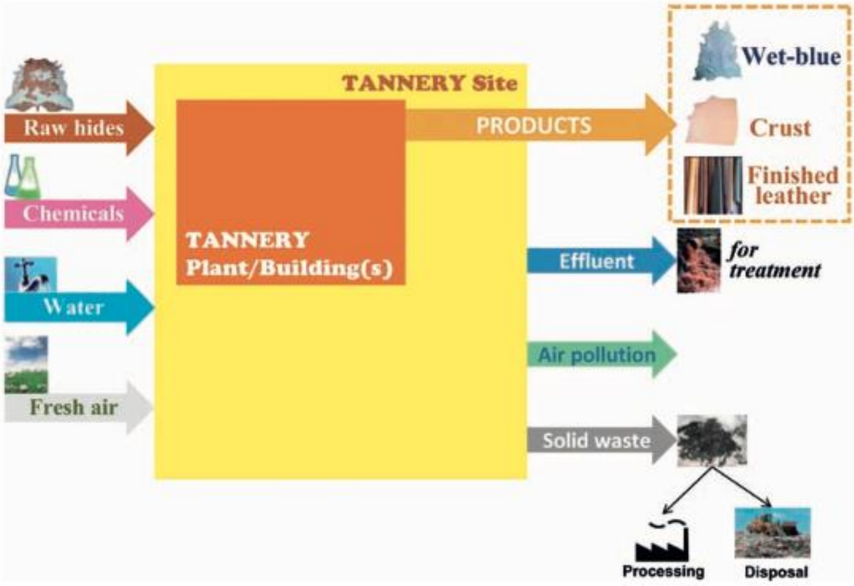

Figure 3.1: Simplified inflow and outflow of Tanning Industry [15]

Regarding the above information, leather industry is not only categorized as one of the highly polluting industries but also, due to the generation of huge amount of solid, liquid and gaseous wastes, it is considered to have an adverse environmental impact. Moreover, in Ethiopia, most of the tanneries do not have treatment facilities and neither environmental management systems. Thus, they simply discharge their wastes into the environment causing critic environmental and health problems in specific areas (including urban and rural areas).

As happening in many other industries from developing countries, the interest of a tannery consists on producing the maximum amount of finished leather to the lowest possible cost. Therefore, the applying of additional costs in order to reduce environmental impact is normally avoided. This way of functioning will probably lead the tannery to commercial success but, environmentally, is unacceptable. It becomes a delicate balance to maintain practically both: keeping the environment sustainable and the growth of the industry. Consequently, a solution needs to be proposed and not postponed. Otherwise, this action will bring serious problems to the management of the environment.

In order to find a logical and feasible solution for appropriate management of solid waste from tanneries, it would be essential to define the nature of the waste and, furthermore, study the location of the industry and way of disposal of its waste.

In this case study, it is planned to assess the actual solid waste management practices of Sheba Leather Industry. The goal would be based on the determination of the amount of solid wastes generated and on their physicochemical characterization in order to propose appropriate treatment options for these tannery solid wastes.

3.2. Statement of the Problem

Tanneries from developing countries usually are not willing to be subjected to the cost of treatment of their waste. This additional cost added to the production cost will have negative effects in their competitiveness in price. Thus, it becomes a great challenge to persuade these industries to use wastewater treatment plants (primary, secondary and tertiary effluent treatment plants) as well as solid wastes practices with minimum cost. In addition, the generated wastes, if untreated, can unfavourably affect the living and non-living things in the environment.

Although the government of Ethiopia has established diverse regulations, proclamations and guidelines with the aim of performing its environmental policy, there are dissatisfactions and concerns on their real implementations. Policies cannot be formulated alone; they need the support of stakeholders working coordinated in order to guarantee its real implementation [2].

Consequently, the country demands more research, innovative and practical solutions to ensure the sustainable development of its industries. This includes the tanning industry. As industrialization progresses, the environmental problem becomes more noticeable. For that reason, it becomes very important to enhance the protection of the environment in the initial step of the industrialization phases.

Accordingly, this study aims to make different suggestions taking into account the existing environmental policy of the leather industry and favouring its implementation. Sheba Leather Industry will be taken as a case study.

3.3. Description of Sheba Leather Industry P.L.C

3.3.1. Introduction

Sheba Leather Industry P.L.C is a tannery located in the northern part of Ethiopia (Tigray Regional State), in Wukro town (45 kilometres from the regional capital Mekelle). This area is known to have good quality livestock, especially goat skin.

Sheba is one of the 16 companies under the group of the Endowment Fund for Rehabilitation of Tigray (EFFORT) and was established with the primary objective of mobilizing regional and national resources to contribute in the economic development of the country in general and Tigray in particular. It was registered as a legal entity since 1993 according the commercial code of Ethiopia with paid-up capital of 118 million Birr (3,068 million euros).

For various reasons, the company remained on project state for ten years and commenced its operation by producing pickle sheep skin and Wet Blue Goat Skin in April 2004 virtually concentrating on export market. These two lines of production continued to be a dominant product of the company until the beginning of 2009 in which most of the products became crust. Starting from July 2010 Sheba has started to produce fully crust, finished products mainly for the local market and different type of shoe for women and men. Starting from February 2011 export of shoe of different styles for summer season has been started to France, Belgium and Sweden [8].

Currently the company has employed more than 947 people. The industry receives wet salted hides and skins (goat and sheep) from the domestic market (mainly goat from Tigray region) and the others from different parts of the country and processes them until obtaining finished leather. As regarded above, it counts with a shoe factory.

About 80% of the total production is exported to the international market as finished leather or shoes while the remaining 20% is sold to the local market also as finished leather or shoes. At this moment, the exportation countries are mainly Italy, China, Russia, France, Belgium, Pakistan, India, Turkey, Sweden and others [9].

3.3.2. Current Status

The company has facilitated some basic information to proceed with the study. From this data it can be assumed that its actual daily soaking capacity is 600 pieces of hides (9,000 kg), 2,000 pieces of sheep skins (3,000 kg) and 4,000 pieces of goat skins (5,600 kg).

The shoe factory daily production consists on 800 pair of leather shoe, 1,200 pairs of canvas and different leather articles for local and export market.

Its daily water consumption is around 600-700 m^3. They use this large amount of water in the different processes applied to the hides and skins. From that water consumption 450-500 m^3 are discharged into the effluent.

Finally, while obtaining finished leather, not only the water is polluted due to the range of process chemicals used but also solid wastes are generated. Sheba's daily solid waste disposal is about 18,000-20,000 kg.

3.3.3 Actual waste management practices

Sheba Leather Industry has a wastewater treatment plant in order to accomplish the national standards and respect environmental regulations. However, as shown in *Table 3.1*, even Sheba has treatment facilities, some parameters of their treated water still differ from the optimum standard values. There are regulations but no effective control regarding industrial effluent discharges.

Leather liquid waste is characterized depending on its nature and, therefore, segregated in four different types:

1. General
2. Chrome
3. Lime (lime, sulphide, sulfhydrate)
4. Saline

The general line is subjected to both, primary and secondary treatment. The primary treatment includes: screening, homogenization and primary sedimentation (coagulation and flocculation). The secondary treatment is based on biological activated sludge system and secondary classifier.

According to the lime line, the company has sulphide oxidation system to oxidize the sulphide to thio sulphate, sulphite and sulphate using permanganate (MnO_4) in order to avoid the formation of hydrogen sulphide gas (H_2S).

Currently, the company is damping the remaining lines (chrome and saline) to the evaporation pond. This is their bottleneck but they are planning to introduce chrome recovery and multiple evaporation system.

The treated water remains in a deposit until the rainy season. During the two months of this season (July and August) the water is discharged into a major stream known as Genfele flowing from the north eastern part of the area to south and south eastern direction. It passes through the Leather Factory and carries all waste disposals from the tannery. The disposal site is made within the stream where the walls are made with loose materials. Hence, the liquid wastes can easily infiltrate and move laterally and vertically downstream through permeable materials where the groundwater velocity is greater [10].

Keeping the above information, the industry should upgrade the existing wastewater treatment plant in order to satisfy the established parameters. Their main concern is the management of salt/chloride content, chrome and color.

A flowchart of the effluent treatment plant as well as some photos of Sheba facilities appear in *Annex B*.

S/N	Type of Test	Results	National Standards
1	MLSS (mg/L)	5375	4000
2	SVI (L/mg)	149	15– 150
3	N (mg/L)	<0.5	30
4	P (mg/L)	4.425	10
5	DO (mg/L)	3.24	>2
6	Chlorides (mg/L)	2573.8	1000
7	COD from Secondary Sedimentation (mg/L)	374.75	NM 500
8	Cr^{+6} (mg/L)	0.25	0.1- 0.25
9	Ammonia (mg/L)	6.88	30
10	Chromium asCr^{+3} (mg/L)	0.25	0.75-2.0
11	Organic acid (mg/L)	41.43	
12	Sulphides (S^{-2}) (mg/L)	0	1-2
13	TDS (mg/L)	10100	
14	BOD (mg/L)	96	No more than 200

Table 3.1: Treated water results in Sheba and national standards

On the other hand, considering the solid wastes, the industry does not provide any kind of solid waste treatment practice. All the solid wastes generated are mixed and disposed in an open dumping area (as shown in *Figure 3.2*) close to the company and surrounded by lands used for cultivation. Some of these wastes have hazardous components and, therefore, the fact of disposing and accumulating these solid wastes without receiving any previous treatment is having a harmful impact.

Moreover, the current landfill is already full and that seems to be the perfect opportunity for Sheba to end with this limitation and propose a proper tannery solid waste management system.

A study was conducted in 2012 to determine the impact of waste disposal from Sheba tannery on surface and groundwater in the surroundings of the factory. It concludes that solid and liquid waste from tannery disposed in the surroundings is affecting the nearby groundwater up to 10 metres depth through recharge. EC, TDS, sodium, sulphate, nitrate and chromium values are relatively much higher in wastewater affecting both surface and groundwater quality downstream. The length of the area affected is about 760 metres from tannery. Therefore, they came up with the suggestion of treating waste disposal, using appropriate filters in deeper aquifers and understanding the adverse effects of high Na and Cr concentrations on the end users. The complete study can be found in *Annex B*.

Figure 3.2: Actual solid waste disposal area (landfill) in Sheba Leather Industry

4. The Leather Industry

4.1. Leather Manufacturing Processes

The leather processing stages can be divided in to four main groups: beamhouse, tanning processes, re-tanning processes and finished processes. There is considerable variation between tanneries, depending on the type of leather being produced. For this reason, a guided visit through all the existing stages of the factory was conducted. After that analysis, it was elaborated a clear and accurate definition of all the exactly operations performed in the study case industry. Thus, the following schematic shown in *Figure 4.1* and the explanation below refer to the leather manufacturing processes carried out in Sheba.

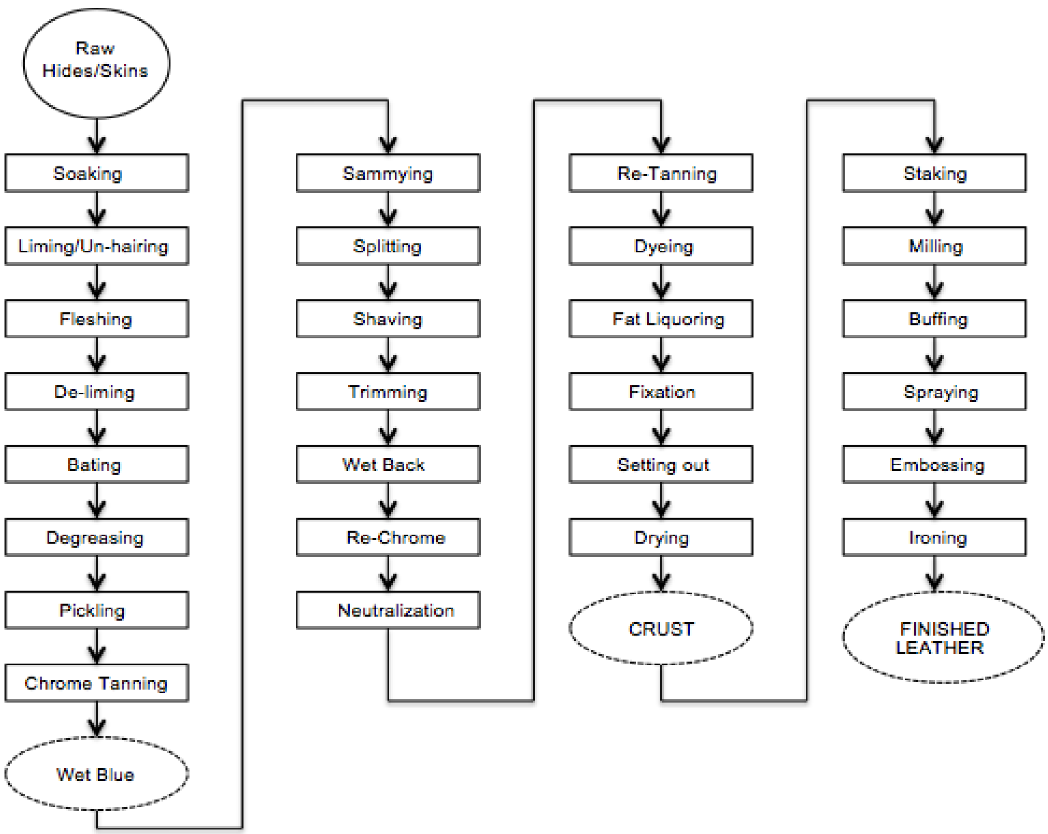

Figure 4.1: Process steps in leather making in Sheba Leather Industry

Annex C may be helpful in order to better understand the overall procedure including photos taken while visiting Sheba Leather Industry.

Operations carried out in the beamhouse, the tanning and the re-tanning areas are performed in water. After re-tanning, the leather is dried and subsequent operations are dry processes [11].

Hides, sheep skins and goat skins are mostly subjected to the same operations. However, those three groups differ in some of them. The following structure defines all the general procedures carried out in the tannery [11-12] and, if necessary, will comment any different pattern.

4.1.1. Hide and Skin Reception and Storage

Sorting / Segregation – Hides and skins, when arrived to the tannery, are sorted into several grades by weight, size or quality.

Remove salt by hand shaking – Wet salted hides and skins are shacked to reduce the amount of salt content in the following operations. This stage generates a solid waste translated in disposal of salt in the landfill.

Raw Trimmings – The unwanted parts of the hides/skins are removed.

Storage – Hides and skins are prepared to start the leather processing and they are stored until taken to the beamhouse.

4.1.2. Beamhouse Operations

The operations carried out in that part of the plant known as the beamhouse are often carried out in the same processing drums, with changes of float and chemicals.

Soaking – Hides and skins are soaked to restore the lost water due to the common salt applied during curing process and, moreover, to remove substances like blood, dirt and conservation salt. This operation is carried out in two steps: a dirt soak to remove the salt and dirt without using chemicals, and a main soak. The second one is performed in alkaline condition (pH ranging from 9.3 to 9.5) and includes wetting agents, sodium carbonate (to adjust pH) and antibacterial as silico fluoride. In Sheba Leather Factory lasts concretely 20 hours.

Liming/ Un-hairing – After soaking process hides/skins are subjected to liming/un-hairing process which consists in treating the materials in alkaline (pH ranging from 12.5 to 13) solution of lime ($Ca(OH)_2$) , sodium hydrosulfide (NaHS) and sodium sulphide (Na_2S). In this operational conditions the hair, epidermis, and to some degree, the interfibrillary proteins are completely removed. In addition, the hide/skin is prepared for the following fleshing process.

In Sheba Leather Factory this process lasts concretely 20 hours and it is conducted in the same drum as the previous operation (soaking).

Exceptionally in case of sheep skins, due to the high amount of hair that they contain, the unhairing operation is done outside the drum, in the ground and using the same chemicals. After this, sheep skins are introduces into the burning drum to continue with the liming operation.

Fleshing – After liming/unhairing process the excessive organic material (flesh and fat) adhering to the hide/skin is removed by a mechanical process called fleshing process.

Fleshing can be performed prior to soaking, after soaking, after liming or after pickling. It is called green fleshing if the removal is done prior to liming/unhairing.
If the process is carried out after liming/unhairing, it is called lime fleshing. Therefore,

in the case study tannery, it should be considered as lime fleshing.

De-liming – De-liming is a chemical process carried out to decrease the pH to 8.0 to 9.0 with the objective of removing the lime added during liming process and to make the hide/skin more receptive to the chemicals that will be used in further stages. The mainly chemical added is ammonium sulphate, an acidic salt.

Bating – Even though hair has been already removed in unhairing operation, some hair roots and pigments are still not removed. For that reason, after de-liming process, hides/skins are exposed to an enzymatic effect for both the removal of these mentioned unwanted proteins, and opening up the structures of hides/skins by a process called bating.

Degreasing – Following the bating process, by addition of aqueous emulsification with solvent extraction or detergents, the degreasing process is performed. The result of it is the removal of the excess natural fat content.
It is particularly important to perform this operation before chrome tanning to avoid the reaction between chromium salts and the greases. In the case that this reaction occurs, insoluble chromium soaps will be formed and they are very difficult to remove.

Pickling – After degreasing process the hides/skins are treated in a solution composed of salt and acids (formic acid and sulphuric acid) to lower pH at an average of 2.8-3.0. It is obtained a homogeneous distribution of tanning material that will be applied in the tanning process.

4.1.3. Tanning Processes

After the hides/skins are conditioned as above, the tanning process is performed. In this process some tanning materials as mineral tanning materials, vegetable tannins and syntans are used. These materials form stable bonds with collagen and give the leather a stable form and a high thermal stability.
In Sheba Leather Industry chrome tanning is applied in acidic solution at pH ranging from 2.8 to 3.0 with penetration purpose. This is the most common option carried out in the leather production because of chrome properties. Mostly chromium sulphate ($Cr(OH)SO_4$) is the basic tanning agent used. However, the alternative of using vegetable and aluminum tanning materials is also widely used. The final product containing chrome obtained after the tanning process is called wet blue because of its colour.

Wet blue product is no longer susceptible to putrefaction because the collagen fibre has already been established by the cross-linking action of the tanning agents. Therefore, stability, resistance to mechanical action and heat resistance increase.

In Sheba Leather Industry, the previous operations including de-liming, bating, degreasing, pickling and tanning are performed in the same drum.

Sammying – After tanning, hides and skins are unloaded and 'sammed' (squeezed between rollers) to reduce the moisture content.

In Sheba, in case of skins, there is a previous selection before sammying in order to satisfy the final customer request.

Splitting and siding for Hides – Only in case of cattle hides, a mechanical operation called splitting is applied in order to split into two layers the hide. The aim of this operation consists on adjusting the thickness of the hide regarding its final request.

Selection of hides – Hides are now selected also depending on their final request.

Shaving – Is a mechanical process applied to adjust the hide/skin thickness and precision based in the costumer order. The resulting pieces of leather shaved off are called shavings.

Trimming – After shaving, the product is again subjected to trimming operations to remove unsuitable parts of the hides/skins.

Weight – Hides and skins are weighted in order to have a control of them.

4.1.4. Re-Tanning Processes

In this stage the wet blue hide/skin is converted into crust leather. The involving chemical and mechanical operations performed compensate structural differences within wet blue leathers and add certain properties to them in order to obtain uniform structure.

Wet Back – Water is added to the hides/skins to re-moisturize them and to remove some unnecessary particles. This operation is performed overnight.

Re-Chrome – Chrome is added again to the hides/skins. This action is important for the final product. Also, this operation is performed overnight.

Neutralization – In this process the free acid present in the tanned hides/skins is removed to assure resistant to boiling and stability in heated conditions. In order to prepare those hides/skins for further steps, they are brought to an appropriate pH ranging from 5.0 to 6.0.

Re-tanning – The re-tanning process is carried out with different objectives such us giving the required uniform fullness by filling the looser and softer parts of the leather, improving the ability to retain consistency and the feel and handle of the leathers. It is carried out at a pH from 3.5 to 5.0.

Dyeing – The dyeing process is applied to give required and consistent colour characteristics over the whole surface of hides and skins. Dyeing provides a good defect cover, suitable color uniformity and maximum colour depth by using the minimum quantity of dye.

Fat Liquoring – In this process the dermic fibres are lubricated to re-establish the fat content lost in the previous operations and, moreover, to provide product-specific characteristics such us softness and fullness.

Fixation – All the chemicals added are fixed to avoid their removal in the further steps. Fibres are closed by addition of formic acid in a pH ranging from 3.0 to 3.5.

Piling – After having carried out the previous operations, hides/skins are unloaded and piled 24 hours before proceeding with the next process.

Setting out – In this process the residual moisture in the hide/skin is reduced from 100% to 65-70% by pressing the leather. In addition, the hide/skin is widened and the grain is flattened.

Drying – The objective of drying is to dry the leather reducing its moisture content from 70% to 20-22%. There is a wide range of drying techniques that may be performed in combination. In Sheba drying is conducted through vacuum drying and/or overhead drying.

For both, hides and skins, vacuum is performed (excepting some skins products such us gloves, garment, sued that cannot go through vacuum machine). Afterwards, overhead drying is carried out. After this stage, crust leather is obtained and it is prepared for finishing operations.

4.1.5. Finishing Processes

Finishing operations are applied to improve the appearance of the leather (softness, elasticity, feels) and to provide the expected characteristics of finished leather. This stage involves the following mechanical operations. The hides/skins are conducted to different procedures depending on the final costumer request (thick, grain, colour).

Staking – Vibrator staking is a mechanical operation applied to soften and stretch the leather. Rotary staking is also performed in case of goat and sheep skins to make them even more soft.

Buffing – Is an optional mechanical operation in which the leather surface is abraded and the resulting dust is removed from the surface. The obtained leather has a soft and opaque surface.

Spray optional – Is an optional mechanical operation applied to spray the leather mostly used for skins.

Embossing or ironing – One of these mechanical operations is applied depending on the leather quality and on grain appearance.
Embossing is performed in pieces of lower quality that have some defects in order to hide them. As an example the final product can be a military shoe.
On the other hand, ironing is applied to pieces of higher quality to make them smooth.

Selection and trimmings – Sometimes, if necessary, the final leather is segregated by size, grade and thickness, and it is trimmed to obtain suitable pieces.

Measuring (area of skin) and packaging – Finally, the area of the finished leather is measured. The final product is packed and prepared to be exported.

4.2. Tannery Waste

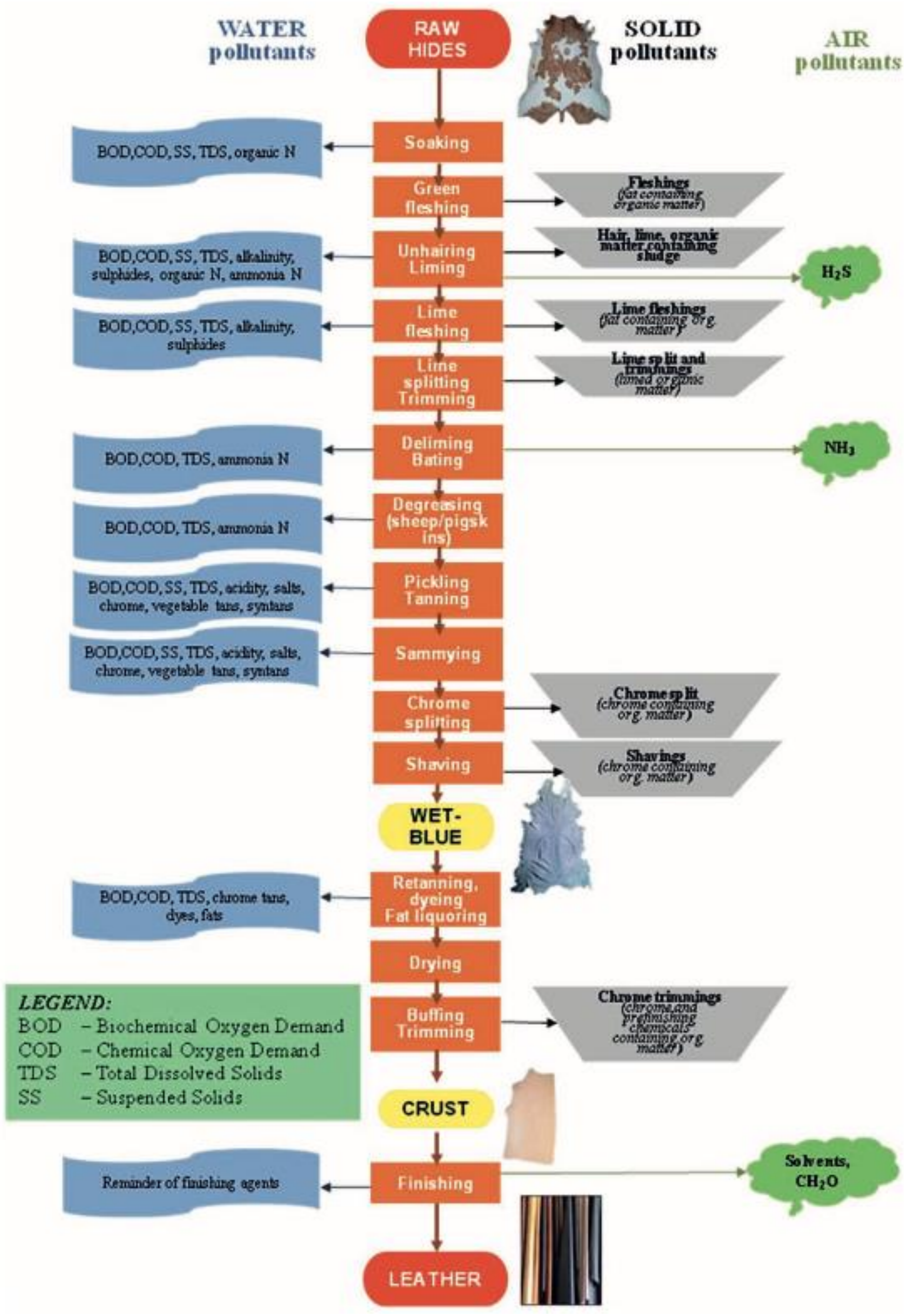

Figure 4.2: Sources and types of pollutants generated in leather processing [15].

As mentioned above, the main releases of leather industries are wastewater, solid residues and odours. In *Figure 4.2* you can have a general idea of the sources and types of pollutants generated in leather processing.

Only 20 – 25 % of the weight of the raw hide or skin is processed to leather. The exact percentage varies depending on the animal species and product specification. Therefore, the rest of the weight plus the unused fraction of the process chemicals either is discharged in the wastewater or arises as a residue at some point in the process. Residues from tanneries can be categorized as by-products, hazardous waste or non-hazardous waste [11].

4.2.1. Liquid and Gaseous Waste

Tannery effluents are considered to be the highest pollutants among all industrial wastes [13]. These effluents are complex in nature and have variations in their characteristics depending on the processes and the case study tannery. They are mainly high in organic and inorganic pollutants. The chemical reagents consumption is very high (about 246 different types in Sheba) as a large amount of them is needed to obtain leather from the initial raw hides and goat and sheep skins. The main inputs include sodium chloride, lime, sulphuric acid, sodium sulphide, basic chromium and others. A relevant part of these chemicals is discharged into the effluent because most of them are not absorbed during the whole process.

Every year 16 millions tons of hides and skins are used in the world leather process. The wastewater discharge from world tanneries is 600 million m^3 approximately per year. That means that on average 45-50 m^3 of wastewater is discharged per ton of raw hide processed [14].

The entire process of tanning is often accompanied by the consumption of large volumes of water. The pollution load discharged into the effluent includes mainly chemical oxygen demand (COD), biological oxygen demand (BOD), total dissolved solids (TDS), total solids (TS), chromium (Cr), sulphides (S^{2-}), sludge and others [15]. You can find an accurate explanation of the environmental effects of the main constituents of tannery effluents in *Annex D.* It has been revealed that the main discharge of wastewater occurs during wet processing stages including beamhouse, the tanning processes and the re-tanning processes. Therefore, these stages contribute above 90% of the total pollution load. The average percentage on each stage is shown in *Figure 4.3* below.

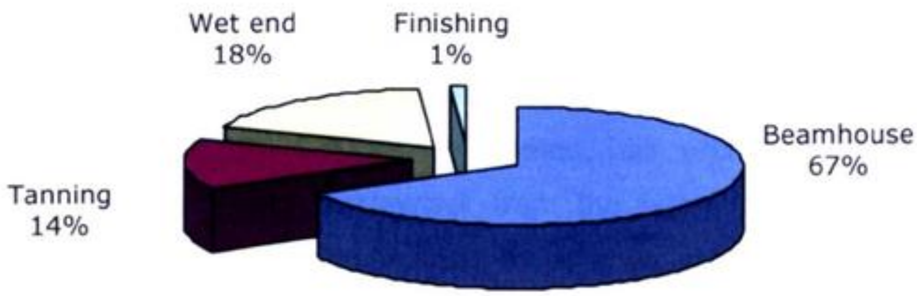

Figure 4.3: Pollution load % generated in every stage of leather processing from 1 tonne of raw hides [27].

Comparing to the magnitude of emissions to water, air emissions are released in relatively small quantities. They have variations among tanneries in accordance of the processes involved. However, air emissions from tanneries are associated with particulates, organic solvents, ammonia, hydrogen sulphide and odour [11].

These emissions to air not only have negative impact beyond the tannery area but also have harmful consequences at the workplace and possibly affect the health of the tannery employers [11].

4.2.2. Solid Waste

Apart of liquid and gaseous wastes, a large amount of solid waste are also generated among all the tannery stages and, moreover, during effluent treatment.

Although the characterization of solid wastes from the tanning industry is well documented, leather wastes generated from each type of leather and process have different characteristics. Thus, in order to find applications of these wastes in various fields it is essential to have accurate information about their nature. In addition, some of these solid wastes contain chromium and are categorised as hazardous wastes. Consequently, a safe disposal needs to be assured.

The solid wastes are mainly generated during fleshing, trimming, splitting and shaving processes but also the sludge generated in the wastewater treatment plant contributes to increase the amount of these wastes [16]. The percentage of solid waste generated in every stage of leather processing from 1 tonne of raw hides is represented in *Figure 4.4*.

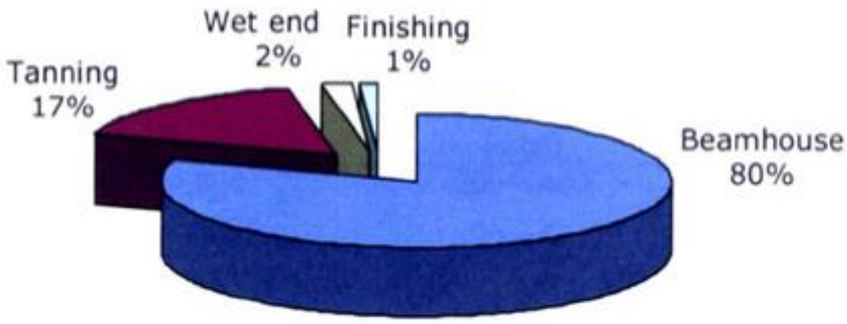

Figure 4.4: Solid waste % generated in every stage of leather processing from 1 tonne of raw hides [27].

According to the data analysed in different studies, only 200 kg of leather is manufactured from 1 tone of wet-salted hide (meaning 20% of the raw hide weight) [1-3]. Therefore, more than 600 kg of solid waste is generated during the leather processing.

An example of the types and quantities of solid wastes generated in a tannery processing one ton of raw hides/skins is represented in *Table 4.1* below.

S.Nº	Nature of solid waste	Quantity (kg)
1	Salt from handshaking	80
2	Salt from solar pans (not realized)	220
3	Hair (pasting ovine)	100
4	Raw trimmings	40
5	Lime sludge (mostly bovine)	60
6	Fleshing	120
7	Wet blue trimmings (grain splits)	30
8	Chrome splitting (bovine)	65
9	Chrome shaving (mostly bovine)	95
10	Buffing dust (including shaving bovine after crust)	65
11	Dyed trimmings	35
12	Dry sludge from ETP	125

Table 4.1: Nature and Quantity of Solid Wastes Generated from Processing 1 Ton of Raw Hides/Skins [17]

4.2.2.1. Characteristics of Solid Waste

During beamhouse operations, fleshings, trimmings and splits are generated. The chemical composition of these solid wastes varies depending on the kind and quality of the raw hides/skins and on the process conditions. Fats and proteins are the main components of these wastes (10,5%). Moisture amounts up to 60% meaning a high water content. Those first solid wastes do not contain chromium compounds [18].

The wastes generated in the tanning process operations are mainly useless splits, trimmings and shavings with diversity on its size and shape. Their chemical composition consists in fat (3-6%) and mineral components (15%). As chromium has been already used they contain 3,5-4,5% of chromium as Cr_2O_3.

Sludge from effluent treatment plants contains mainly water (up to 65%), organic substances (30%) and chromium (III) (around 2,5%) [18].
One of the major environmental problems in the leather industry is the disposal of sludge contaminated by chromium produced as a by-product of wastewater treatment [19].

4.2.2.2. Environmental Impacts

The tannery solid wastes have different characteristics depending on the chemical and mechanical processes applied to the raw hides/skins. It is very important to analyse the nature of these wastes in order to assure a safe disposal or application of them. Otherwise, environmental problems may appear. Shacked salt, used to preserve hides or skins, if thrown into open dumping areas or accumulated in piles outside the

tanneries, is likely to create groundwater pollution when rain washes it away. Hair waste and lime sludge discharged into the effluent can produce choking of treatment pipes. Trimmings, raw and green fleshings, limed fleshings and splitting waste putrefy easily producing noxious smells. Some of the bio-degradable tannery solid wastes cause volatile organic compounds emissions and, moreover, are sources of pathogenic bacteria.
Chrome tanned shavings hardly discompose and they lead to disposal problems [20]. Primary and secondary sludge are also putrescible [21].

Beyond all the solid wastes generated, fleshing and sludge are the ones emanated in higher quantities. It is reported that approximately 140-200 kg of fleshing are generated per tone of leather processed. It contains about 80-90% moisture, 6-12% dry volatile matter and 4-8% ash and mineral substances. It causes a serious disposal problem.
Similarly, large quantity of sludge is produced when treating wastewater from leather industries. It is considered as a hazardous waste because it contains chromium. In the study case in Sheba, there is no controlled and secured landfill available and, therefore, all these solid wastes mentioned above, including the sludge, are dumped in open areas randomly without receiving any previous treatment. Consequently, this inappropriate disposal of solid waste including chrome-containing wastes has negative environmental impacts.

As mentioned before, while the tanning operations are being carried out, chromium tanning agents are being added. Unfortunately, only a fraction of these agents remains in the skins. The other fraction stays in the tanning bath and ends up in the sludge. This chromium is mostly discharged as Cr (III) [19]. Very fine colloids are also formed and then, stabilized by the chrome (III). These components are highly resistant to biological breakdown, and the biological process in treatment plants and in surface waters is inhibited.

If finally breaks down, chromium hydroxide precipitates and will persist in the ecosystem for a long period of time. It has toxic effect even we find it in low concentrations. Chromium not also can disrupt the food chain for fish life but also can inhibit photosynthesis.

Generally chrome waste from leather processing poses a significant disposal problem to both, the environment and human health. The sludge tends to concentrate heavy metals and potentially pathogenic organisms (viruses, bacteria etc.) as well as poorly biodegradable organic compounds.

Thus, an accurate knowledge of the consequences of solid wastes generated by tanneries should be taken into account in order to reduce their environmental impacts.

5. Policy and Legal Framework for Environmental Management

5.1. Environmental Policy of Ethiopia

The Environmental Policy of Ethiopia was approved in 1997 becoming the first key document that collected environmental sustainable development principles. The aim of the Environmental Policy of Ethiopia is to improve and enhance the health and quality of life of all Ethiopians and to promote sustainable economic and social development through the suitable management and use of resources and the environment as a whole in order to meet the needs of the present generation without compromising the ability of future generations to meet their own needs (EPA, 1997) [22].

In order to guarantee its effective implementation, the Environmental Policy of Ethiopia strengthens the creation of an organizational and institutional framework from federal to community levels. Furthermore, it provides a number of guiding principles associated with principles of sustainable development to ensure Environmental Impact Assessment (EPA, 1997).

5.2. Establishment of Environmental Protection Organs

Proclamation 295/2002 establishes the organizational requirements and identifies the need to establish a system that enables coordinated but different responsibilities of environmental protection agencies at federal and regional levels. The Proclamation indicates the duties of different administrative levels responsible for applying the law.

5.3. Environmental Pollution Control

Proclamation No. 300/2002 [23] on Environmental Pollution Control principally attempts to ensure the rights of citizens to a healthy environment by the imposition of obligations that will protect the environment of the country. The proclamation has its base on the principle that each citizen has the right to live in a healthy environment and, also, has the obligation of protecting the environment of the country. The law attends to the establishment of environmental quality standards for water, soil and air, the management of both, municipal and hazardous waste, and monitoring of pollution. The Proclamation serves as a guide to enable the development of the main environmental standards applicable in Ethiopia. Not accomplishing these standards can lead to criminally punishable offences.

Additionally, it supports the Regional Environmental Authority and/or the EPA to select environmental inspectors in order to control environmental pollution. In accordance with this fact, inspectors from the relevant regional environmental agency or from EPA are allowed to visit, without previous announcement, any land or premises at any time, at their judgement.

5.4. Solid Waste Management

Proclamation N0. 513/2007 aims to promote community participation in order to prevent adverse effects and enhance benefits resulting from solid waste. It guides urban local governments in order to define how to prepare solid waste management action plans.

Consequently, solid Waste Management Proclamation No. 513/2007 states (Article 5.1) that Urban Administrations shall guarantee the participation of the lowest administrative levels and their respective local communities in designing and implementing their solid waste management practices. Article 5.1 establishes that each urban administration or Region should determine its own schedule in order to prepare its solid waste management plan and report of implementation. Any additional information required will be conceded from the Regional Environmental Protection Authorities and federal EPA.

5.5. Prevention of Industrial Pollution Regulation

Proclamation 300/20202 [24] was developed by the Federal Environmental Protection Authority and confirmed by the Council of Ministers in order to prevent industrial pollution while assuring compatibility of industrial development with environmental conservation.

This Regulation stipulates significant obligations to industrial operators. A factory below these regulations is committed to prevent or minimize the generation and release of pollutants in order to satisfy the environmental standards. Additionally, industrial operators are supposed to implement internal environmental monitoring systems, control the rate of pollutants generated, and describe the disposal mechanisms applied. As a consequence, following Regulation 159/2008, industries are enforced to present annual reports declaring the previous statements.

5.6. Environmental Guidelines and Standards

Between 2008-2010 EPA [25] had established preliminary environmental standards and guidelines for several industrial sector activities and ambient environmental qualities. They include the draft Guideline on Sustainable Industrial Zone/Estate Development. Few years later, the Environment Council selectively accepted some of the industrial environmental standards for twelve specific industrial sub-sectors. The leather sector is included and, therefore, should respect the industrial emission standards.

Although Ethiopia has incorporated useful environmental laws, additional policy mechanisms and instruments are needed to compel the above law. It is noticeable the existence of serious weaknesses in the integration of environmental policies in the tanning sector as a tool for the promotion of sustainable development.

According to Gashaw (2007), to guarantee its sustainable development, every tannery should satisfy five pillars by being: socially acceptable, ecologically protective, economically productive, and environmentally just and efficient.

5.7. Provisional Standards for Industrial Pollution

This standard among other things provides guidance on effluent and emission standards [26]. Emission and effluents standards for tannery in Ethiopia (2003) are given below:

No	Constituent Group or Parameter	Emission Limit Value (mg/l)
1	Temperature	40 ^{0}C
2	pH	6 – 9 pH units
3	BOD5 at 20 ^{0}C	>90% Removal or 200 mg/l
4	COD	500
5	Suspended Solids	50
6	Total Ammonia (as N)	30
7	Total Nitrogen (as N)	>80% Removal or 60 mg/l
8	Total Phosphorus (as P)	>80% Removal or 10 mg/l
9	Oils, Fats, and Grease	15
10	Mineral Oil (Interceptor)	20
11	Chromium (as total Cr)	2
12	Chromium (as Cr VI)	0.1
13	Chloride (as Cl)	1000
14	Sulphide (as S)	1
15	Phenols	1

Table 5.1: Tannery Effluent Standard Emission Limit Values for Discharges to Water [8]

No	Substance	Concentration Limit (mg/Nm3)
1	Total Particulates	50
2	VOCs (degreasing)	50
3	VOCs (finishing)	75 g/m2 product produced
4	Total hydrogen sulphide, sulphides and mercaptans (as S)	5 ppm v/v
5	Ammonia	40 ppm v/v
6	Acid vapors (as HCl)	30

Table 5.2: Emission Limit Values for Emissions to Air [8]

5.8. Conclusions

As mentioned previously, a tanning industry will have harmful effects on both, human beings and animals, as well as on the eco-system in case the waste generated is not properly discharged or disposed.

For that reason, the government of Ethiopia formulated environmental policy and different laws mentioned above. Starting from the Constitution, there exist diverse regulations, proclamations, standards and guidelines to guarantee the implementation of the policy.

Despite the contrary, the integration between these laws and the industrial policy is poor and even though the initiative of CRGES in 2011 meant one step forward, there is a weak implementation in the environmental policy. Further policy instruments and innovative practical mechanisms are required.

The previous discussions reveal that the government needs foreign exchange and requires a rapid economic growth. Stakeholders such as Ministry of Industry and Leather Industry Development Institute have the Understanding of environmental Issues. However, they are in defaulting situation regarding to the environmental sustainability. It seems they have approach economic benefits and foreign exchange earnings rather than environmental issues. Nonetheless, despite the great desire to economic growth, after CRGES there is more awareness of environmental protection issues in industrialization process than before.

6. Solid Waste Management

6.1. Introduction

Solid waste management is the collection, transportation, storage, recycling or disposal of solid waste. All of these processes need to be legally, socially and environmentally acceptable in order to guarantee the public health and protect the environment [26]. The provision of appropriate treatment and/or disposal facilities is key factor in selecting any waste management option. The selected management will be the one that provides the best environmental option considering the principle of sustainable development (Petts and Eduljee, 1994; Williams, 2005). There are other factors that must be taken into account, among them, capital investment, costs of the facility, proximity/availability to the source of waste arising, and operating and maintenance costs [27].

Treatment process options can be classified into four basic types:

• Physical
• Chemical
• Thermal
• Biological

The aim of these treatment processes is stabilising the waste, reducing or eliminating their intrinsic toxicity, consequently decreasing their impact on the environment. In other cases, these treatments consist on obtaining a useful product from the waste.

6.2. Integrated Waste Management

Integrated waste management (IWM) is defined as the selection and application of appropriate technologies, techniques and management plans to achieve specific waste management goals [28].

In order to guarantee a successful and proper integrated solid waste management plan, it is compulsory the interaction between a wide range of disciplines including: legal, planning, financial, environmental, administrative, architectural and engineering functions. In *Figure 6.1* the four basic waste management strategies defined by IWM are represented. They are 1) source reduction, 2) recycling and composing, 3) combustion (waste-to-energy) and landfills [28].

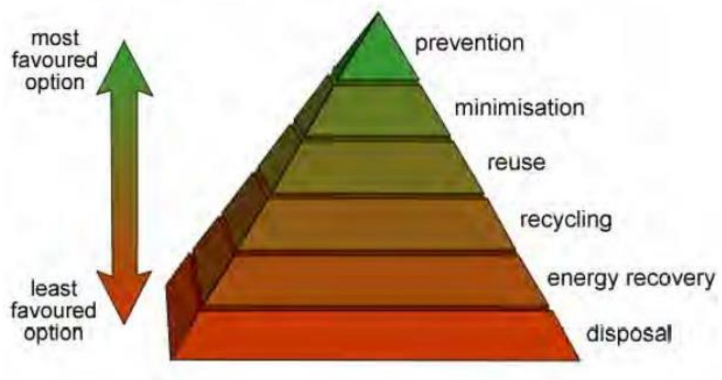

Figure 6.1: Waste Management Hierarchy

Thus, waste management is based on this concept of a hierarchy of options where, not producing the waste in the first place, is the most desirable alternative.
Waste is increasingly being considered as a valuable resource to the industry and a major economic sector. Therefore, dealing with the waste not only has environmental positive effects but also economical, creating jobs and business opportunities [27].

6.3. Waste-To-Energy (WTE) Technology

Waste-To-Energy methods aim to generate energy by managing solid waste. A wide range of technologies and different procedures can be applied in order to transform waste into energy. Among them, the two main methods that obtain energy from the organic fraction of waste (biodegradable as well as non-biodegradable) are Thermo-chemical Conversion and Bio-Chemical Conversion [29].

6.3.1 Thermo-Chemical Conversion

Thermo-chemical conversion process is the thermal de-composition of organic matter to generate heat energy, gas or fuel oil. These processes are suitable for wastes having low level of moisture/water content and high amount of organic non-biodegradable matter. The main processes included in this group are Incineration and Pyrolysis/Gasification [30].

6.3.2. Bio-Chemical Conversion

Bio-chemical conversion process produces methane gas or alcohol by an enzymatic decomposition of organic matter carried out by microbial action. In this case, these processes are appropriate for wastes having high content of moisture and high amount of organic biodegradable matter. These conditions are favourable for microbial activity. The main processes under this category are Anaerobic Digestion (Bio-methanation) and Composting [31].

6.3.3. Suitable Processes for Case Study Tannery

The processes mentioned previously were explained to the manager of Sheba Leather Industry. After discussing about them, taking into account the company preferences and the existing resources of Wukro (Ethiopia), the composting method was found to be the most feasible and appropriate solution.

Composting is an excellent waste management technology. Instead of disposing the wastes, you can disinfect them obtaining a resource. Additionally, it is proved that composting method has more environmental benefits than incineration or landfilling and its implementation in developing countries has favourable repercussions for the overall society. It can derive in the abolition of important food-borne diseases, contribute to the improvement of soil conditions, preserve moisture in the soil and provide nutrients for crop production [32].

On the other hand, the factory is concerned about how to deal with the sludge from the wastewater plant that is considered a hazardous solid waste as it contains chrome.

Therefore, in order to perform the study according to Sheba’s preferences, the composting option and the management of the sludge were deeply studied with the support of Spain’s tanneries methodology. The research carried out is given as follows.

7. Composting

7.1. Definition of Composting (Process) and Compost (Product)

Composting is the biological decomposition of biodegradable organic waste into simpler compounds carried out by a microbial community composed of various populations in aerobic conditions and in the solid state. It is an exothermic process in which energy is produced in form of heat and, subsequently, the temperature of the mass increases [33].

The process of composting depends on the activity of microorganisms, which can be found in the material to be composted or added to it. Suitable conditions of temperature, moisture and oxygenation are required to assure the development of the decomposition activity [34].

It is a spontaneous process that goes through a thermophilic phase preceded and followed by two mesophilic phases. There exists a temporary release of phytotoxins (intermediary metabolites, ammonia, etc.) during composting resulting in a final product completely free of phytotoxicity and, therefore, advantageous for plant growth.

As shown in *Figure 7.1*, composting generates carbon dioxide, water, minerals, and stabilized organic matter (compost). The process first begins with the decomposition phase in which oxidation of easily degradable organic matter occurs. After that, the second phase called stabilization is carried out. During this phase slowly degradable molecules are mineralized and also more complex processes such as humidification of ligno-cellulosic compounds take place [33].

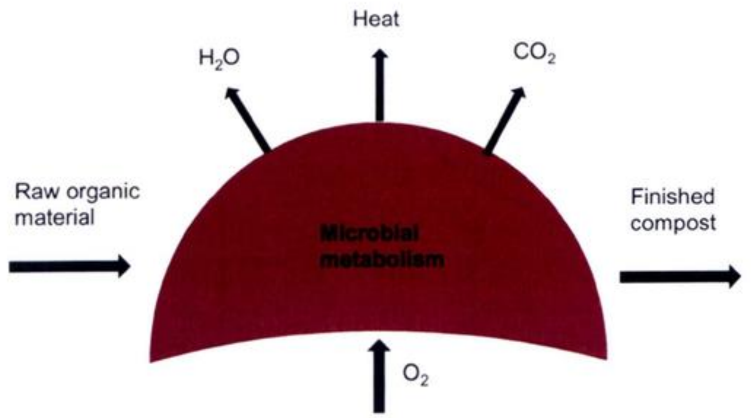

Figure 7.1: The composting process for raw organic material, and inputs and outputs of the composting process

The principal product generated is called compost, which can be defined as a sanitized and stabilized product that is compatible and safe to use for agricultural purposes [27].

Compost has experimented:

(1) An initial, rapid stage of decomposition
(2) A stage of stabilization
(3) An incomplete process of humidification

The three main reasons why the fresh organic matter is converted into compost are:

(1) The overcoming of the phytotoxicity of fresh non-stabilized organic matter
(2) The decreasing of the presence of agents (parasites, viruses, fungi, bacteria) that are adverse to man, plants and animals to a non-risky level for health
(3) The obtaining of a soil conditioner or an organic fertilizer, reusing organic wastes and biomass

7.2. Composting Process Description

Composting process can be defined as a consecution of continuous cultivations having each of them their own chemical (the available substrate), physical (e.g., temperature) and biological (e.g., microbial community composition) properties and effects. The constant changes complicate the study of the process [35]. However, it is accepted that composting is mainly a four-phase process according to the temperature that is directly proportional to the microbial activity during the overall process. The temperature of the mixture materials rises as the rate of microorganisms increases. As a result, the temperature becomes a function of the accumulated heat produced metabolically, and, subsequently the temperature remains a determinant of metabolic activity. Therefore, controlling the temperature within the composting process is crucial [34]. The four composting stages are summarized as follows:

7.2.1. Mesophilic Phase (25-40ºC)

This starting phase begins at ambient temperature and the mesophiles microorganisms immediately multiply in the mass. The predominant compounds like proteins and sugars, which are energy-rich and easily degradable, are degraded by primary decomposers such as fungi, bacteria and actinobacteria. It is proved that the number of mesophilic organisms in the initial substrate is three times the number of thermophilic organisms and the activity of primary decomposers results in an increase of the temperature as well as in a generation of organic acids that lower the pH.

7.2.2. Thermophilic Phase (35–65ºC)

When the temperature reaches 40ºC, thermophiles microorganisms act transforming the nitrogen into ammonia and replacing the mesophilic flora. An alkaline pH is created [34]. The decomposition continues and it accelerates until temperature reaches 60ºC. Thermophilic fungi have their maximum rate at temperatures between 35 and 55ºC while higher temperatures do not allow fungal growth. Thermotolerant and thermophilic bacteria and actinobacteria continue their activity also at higher temperatures.

The temperature range of psychrotolerant, mesophilic, and thermophilic organisms and their generation times are shown in *Figure 7.2.*

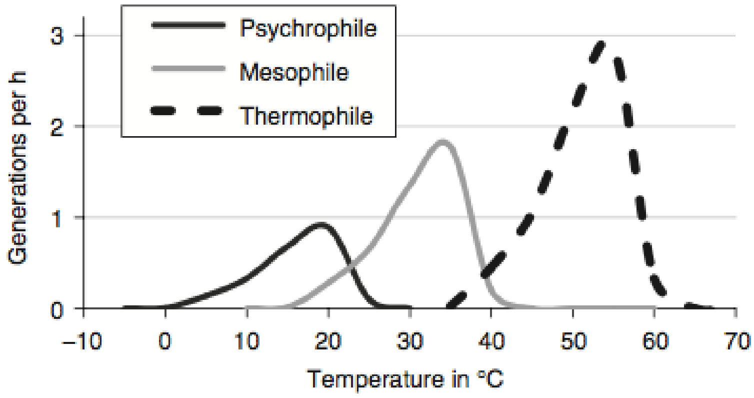

Figure 7.2: Temperature range of Psychrophile, Mesophile and Thermophile and their generation times per hour [33]

This phase is critical for hygienization. During its development insect larvae and weed seeds are killed as well as human and plant pathogens are destroyed. The presence of mostly actinobacteria and the reached temperature during this stage permit hygienization through the generation of antibiotics. Temperatures should not exceed 70ºC in order to avoid the death of mesophiles. This fact may retard the recovery after the temperature peak but can be prevented by suitable measures of recolonization [35].

Distinctive zones of a compost pile reach different temperatures. Therefore, it is very important to move every part of the substrate to the central, hottest part of the pile by regular turning [35]. As represented in *Figure 7.3*, four main zones can be distinguished within a pile:

- The outer zone which is the coolest and satisfactorily supplied with oxygen
- The upper zone which is the hottest zone and normally well supplied with oxygen
- The inner zone which is not well supplied with oxygen
- The lower zone which is hot and well supplied with oxygen

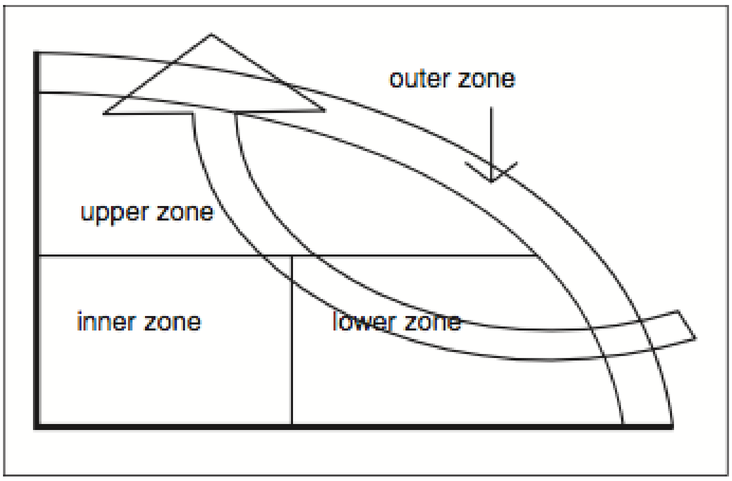

Figure 7.3: Cross section of a compost windrow [33]

7.2.3. Cooling Phase (Second Mesophilic Phase)

In this stage the temperature starts to decrease due to the exhaustion of substrates that stops the activity of thermophilic organisms. Mesophilic activity re-starts recolonizing the substrate and the pH lightly decreases. An increasing number of organisms capable of degrading cellulose and starch, such as fungi or bacteria, describe this second mesophilic phase [33].

7.2.4. Maturation Phase

Secondary reactions such as condensation and polymerization of humus are performed during maturation phase at ambient temperature [34]. The composition of the microbial community is completely modified. Commonly, the number of bacterial declines while the proportion of fungi increases. Non-degradable compounds are produced and predominate [33].

7.3. Process Drivers

There are considerable factors that influence composting process such as the type of waste, the environmental conditions and the composting technique applied. Therefore, it is vital to define and control the following factors presented below. [34].

The main factors affecting decomposition of the organic matter during composting process are moisture and oxygen. In addition, two more factors are significant for composting: temperature and nutrients, specially carbon and nitrogen [32].

The rate of decomposition is a function of microbial activity. Consequently, the following conditions can reduce or limit this activity [32]:

- Low moisture
- Low oxygen content
- Lack of available carbon or degradable organics
- Lack of free pore space

7.3.1. Substrates

In composting, the substrate can be defined as the waste that is going to be composted. Thus, to assure the feasibility of the process it is essential to evaluate the physicochemical characteristics of the substrate. Basically, the appropriate balance and concentration of the nutrients as well as the availability of these nutrients to the microorganisms will determine the viability of composting [35].

On one hand, the most important chemical characteristics are related with molecular complexity, size and nature as well as elemental makeup of the molecules. On the other hand, the pertinent physical characteristics are mainly linked to moisture content and particle size.

The microorganisms will assimilate the containing-nutrients of substrate depending on its complexity and of the nature of its molecular structure. Therefore, the assimilability of these nutrients becomes function of the ability of those microorganisms to synthesize the enzymes that break down other complex compounds. These complex compounds are transformed into simpler compounds or elements that can be used for the microbes' metabolism and synthesis of new cellular material. In case that all the microorganisms are not provided with the suitable enzymes, the whole substrate will not be transformed and will remain in its initial form. In order to avoid this situation, the substrate may include the necessary nutrients mentioned below.

Starches, sugars, and fats decompose or mineralize much faster than proteins or cellulose, whereas lignin is very resistant to mineralization [49].

7.3.1.1. Types and Sources of Nutrients

Microbes' macronutrients are considered to be nitrogen (N), carbon (C), phosphorous (P) and potassium (K). Among the micronutrients, manganese (Mn), cobalt (Co), magnesium (Mg), copper (Cu) and other elements can be found. Calcium (Ca) is on the way between the macro and micronutrients [35].

It is very important to clarify that the presence of large concentrations of nutrients in a substrate does not guarantee appropriate conditions for composting if these nutrients are in a form that is not available for the microorganisms and, hence, that cannot be assimilated.

Therefore, taking into account the fact that the availability depends directly on each microbe's enzymatic makeup, it can be said that some microbes will attack, degrade and use organic matter coming from freshly generated waste while other groups will only use as nutrients the intermediates/decomposition products. This fact can be summarized as decomposition and, subsequently, composting process involves several activities. These activities are carried out by a succession of certain groups of microbes in which each group will enhance appropriate conditions for its successor group.

7.3.1.2. C:N

Taking into account the nutritional needs of the microorganisms, it can be said that C:N ratio is the most important factor requiring attention during composting process. Experience shows that all the other nutrients in typical organic waste are found in appropriate amounts and ratios.

Although it depends on the components of the compost pile, a ratio of organic carbon to total nitrogen (C:N) in the starting material of about 25 to 30:1 can be considered as optimum ensuring a satisfactory composting process [36]. Active microbes in composting use about 30 parts of carbon per each part of nitrogen during their metabolism. A large percentage of the carbon (about 20 parts) are oxidized to CO_2 while the 10 remaining parts are converted into protoplasm, cell wall or membrane, and storage products. Consequently, much more carbon than nitrogen is needed. Carbon can be considered as “food” and nitrogen as the digestive enzymes.

If C:N ratio is too high, not enough nitrogen is available for the growth of microorganisms and biological activity decreases slowing dramatically the composting process. On the other hand, if C:N ratio is too low a loss of nitrogen through ammonia volatilization may occur producing odors and polluting the atmosphere [37]. In addition, the organic fertilizer obtained will be less valuable because of the reduction of nitrogen content of the final product. A combination of high temperatures and elevated pH level (8.0-9.0) are likely to cause nitrogen lost as ammonia-N.

In a well-performed process, the C:N decreases constantly because of the biological mineralization of carbon compounds and loss as CO_2. In small-scale composting, in case carbon and nitrogen analyses are not financially feasible, the C:N ratio can be considered adequate if the ratio of green fresh waste to dry, non-green waste is volumetrically about 1:4.

7.3.2. Environmental Factors

Composting is affected by different environmental factors as it is considered a biological process. These factors determine the rate and extent of decomposition. Among them, temperature, pH, moisture content, and aeration are of high interest.

7.3.2.1. Temperature

Composting is an exothermic process that produces a large amount of energy. About 40-50% of this energy, is used by the microbes for the synthesis of enzymes. The remaining energy is lost in form of heat in the mass causing an increase of temperature that can reach 70-90ºC.

Microbial activity is traduced in temperature variations. During these changes this microbial population evolves and changes. This fact is essential as it enables the microorganisms to metabolize the diverse compounds of the waste. Temperatures rise from ambient to mesophilic and then to thermophilic as shown in *Figure 7.4* [32].

The optimum level of temperature that enhances microbial diversity and biodegradation ranges from 30 to 45ºC. Extremely high temperatures do not permit microbial growth. Therefore, in order to optimize the composting process, a temperature control should be conducted with a set point between 30 and 45ºC. However, the thermophilic phase should not be entirely eliminated as it permits hygienization reducing pathogenic agents [33]. Temperature dropping close to ambient indicates that the process is nearly completed and that the compost is, probably, stable and mature [32].

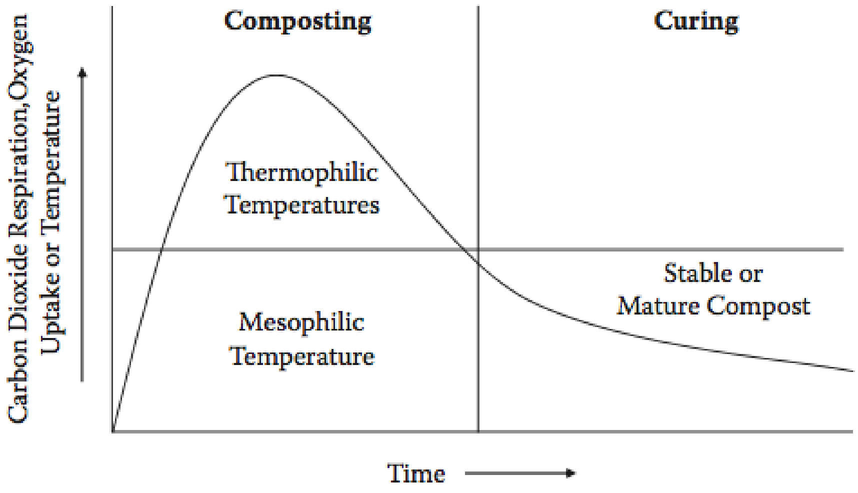

Figure 7.4: Changes in temperature and carbon dioxide respiration during composting [32]

7.3.2.2. pH

The optimum range of pH is between 5.5 and 8.0. However, composting is well conducted in a wide range of pH (from 3.0 to 11.0). Fungi can resist a pH range of 5.0 to 8.0, and bacteria prefer a nearly neutral pH (around 6.0-7.5) [38].

The pH not only determines microbial activity but also works as an indicator of the evolution of the process. Firstly, in the mesophilic phase, pH level begins to drop because of the activity of acid-forming bacteria. When this acidification phase ends, the pH increases up to 8.0-8.5 at the end of the process. Whereas a significant decrease on pH value may result in anaerobic conditions, high values may cause loss of nitrogen through the volatilization of ammonia. However, as the range in composting is so wide, difficulties due to an excessively low or high pH value are uncommonly encountered.

7.3.2.3. Moisture Content

Water is indispensable for all microbial activity and must be present in suitable amounts throughout the composting process. Commonly, poor moisture (below 40%) results in rapid dehydration of the mass and produces physically stable but biologically unstable compost. In these conditions the rate of microbial activity decreases. When the moisture content is less than 8-12%, microbial activity is mostly ceased. On the other hand, when moisture content is excessive (moisture level exceeding 60%), the pore space can be filled with water resulting in a lack of oxygen and therefore, a decrease in microbial activity. Moreover, this excess can cause an anaerobic process and, therefore, a slower process and low quality final compost.

Moisture control is essential in composting cycle as it is a drying process and water is lost during the rise of temperature [39]. Each material has its own water-holding capacity and, therefore, an exact generalization about the optimal starting moisture level cannot be made. For example, fibrous materials must be in the range 75-85 %, while fresh vegetable is allowed to have moisture up to 50-60%. However, the optimum level appears to be about 50-60% in the starting material. At the end of the composting process, the water content should be lower (near 30%) in order to avoid any possible biological activity in the stabilized product.

It is important to understand that the type of technology applied, the ambient conditions and the temperature during the composting process affect the moisture loss. As an example, more moisture content is lost in turning systems in comparison with static systems. The higher the temperature in the composting mass, the greater the loss of water [32].

7.3.2.4. Aeration

Composting, as an aerobic process, requires oxygen. The provision of this oxygen is accomplished through aeration and is greatly influenced by the technology and the system applied in composting. Appropriate amount of oxygen is provided by turning process and convection in windrow composting. In case of aerated static pile (ASP), agitated bed, and other systems, blowers are used to reach this objective [40].

As mentioned previously, the microbial population requires oxygen. The availability of this oxygen is a function of porosity. Therefore, sufficient porosity through the matrix is essential. Porosity determines the availability of a source of air (oxygen) to reach the microorganisms but total porosity is not an indication of available porosity. In order to explain this fact a new parameter is introduced: the free air space (FAS).

FAS is defined as the portion of the pore space not occupied or blocked by water. It is commonly calculated by the following equation that relates the bulk density (BD) to the specific gravity (SG):

Free air space (FAS) = 100 (1 – BD/SG) × dry mass

This pore space allows air to spread through the mass and provide oxygen to the microorganisms. This is represented in *Figure 7.5,* where the amount of FAS is reduced due to the effect of water blocking some of the pores.

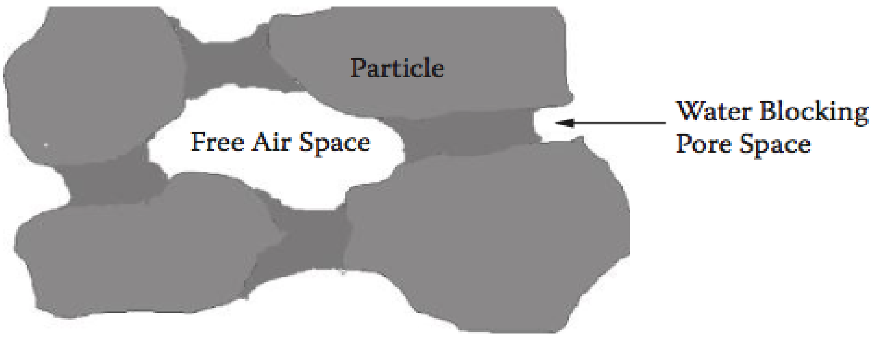

Figure 7.5: Free pore space in relation to blocked pores with water [32]

Oxygen levels above 10% are usually provided. When the oxygen level is below 5%, anaerobic microorganisms begin to exceed aerobic ones. In order to avoid this situation and permit the microorganisms the maintenance of their metabolic activities, a constant supply of oxygen is required [32].

7.3.3. Microorganisms in Composting

A wide range of microorganisms is responsible for the completion of the aerobic decomposition of organic matter. Among them, the most numerous are bacteria. They are the primary biodegraders that decompose the more readily available carbonaceous compounds. Other microorganisms as fungi ad actinomycetes are also present in composting. They are presented in *Table 7.1.*

Microorganisms Identified in Composting

Bacteria	Actinomycetes
Aerobacter (aerogenes)	*Nocardia brasiliensis*
Bacillus megatherium	*Thermomonospora viridis*
B. stearothermophilus	*T. curvata*
B. cereus	*Micromonospora parva*
B. Mycoides	*M. vulgaris*
	Thermoactinomyces vulgaris
Pseudomonad sp.	*Actinoplanes* sp.
(Seven isolates)	*Thermopolyspor polyspora*
Flavobacterium sp.	*Pseudonocardia*
Micrococcus sp.	*Streptomyces violaceoruber*
Sarcina sp.	*S. thermoviolaceus*
Cellumonas folia	*S. rectus*
Chondrococcus exiguus	*S. thermofuscus*
Mycococcus virescens	*S. thermovulgaris*
M. fulvus	*Thermomonospora fusca*
Thibacillus thiooxidans	*T. glaucus*
T. denitrificans	
Proteus sp.	

Table 7.1: Microorganisms identified in composting [32]

Fungi	
Rhizopus nigricans	*Absidis orchidis*
Rhizoctonia sp.	*Rhizopus arrhizus*
Geotrichum candidum	*Candida (parapsilosis)*
Mucor pusillus	*Cladosporium herbarum*
Penicillum digitatum	*Rhodotorula rubra*
Mucor racemosus	*Aspergillus tamarii*
Torulopsis sp.	*Zygorhynchus vuilleminii*
Aspergillus flavus	*Trichosporon cutaneum*
Absidia (ramosa)	*Verticillium* sp.
Saccharomyces sp.	*Synecephalastrum* sp.
Pulluloria sp.	*Pichia* sp.
Pythium sp.	*Cylindrocaron* sp.
Hanisenula sp.	*Chaetomium (thermophile)*
Trichoderma koningi	*Lipomyces* sp.
Talaromyces (Penicillium) duponti	*Sporotrichium thermophile*
Stysanus stemonitis	*Fusarium moniliforme*
Glibotrys (alaboviridis)	
Humicola insolens	
Humicola griseus var. *thermoideus*	

Protozoans	Algae
Chilomonas (paramecium)	*Hormidium (nitens)*
Cyathomonas (truncata)	*Vaucheria (terrestris)*
Lycogala epidendrum	*Euglena mutabilis*
Cercomonas (crassicanda)	*Protococcus vulgaris*
	Dactylococcus (bicandatus)
	Chlorococcum humicola
	Microcoleus vaginatus
	Porphyridium (cruentum)
	Kentrosphaera sp.
Diatoms (unidentified)	

Table 7.1: Microorganisms identified in composting [32]

7.4 Stability, Maturity, and Phytotoxicity

Stability, maturity, and phytotoxicity are terms usually confused. It is very important to characterize the differences between them in order to understand the quality of the final compost [32].

Stability is a function of the composting process related with the amount of time the process is performed as well as a stage in the decomposition of organic matter. It is a function of the biological activity and, the slower or lower the activity, the more stable is the compost. Therefore, a stable product is not supposed to rise its temperature and, neither, release odors. On the other hand, if an unstable compost is applied to the soil, the nitrogen that is commonly available to plants will disappear.

Maturity is an organic and chemical condition of the compost also related to the process that indicates the presence or absence of phytotoxic organic acids.

Phytotoxicity specifies any organic or inorganic substance that is toxic to plants. Although it is not necessary related to the process, it could indicate that a chemical that can be damaging to the plants has been obtained in the waste or otherwise included in the process.

7.5. Course of the Process

Describing the common sequence of events that take place when composting process is being performed successfully can be helpful in order to understand how to develop an appropriate program for monitoring compost systems. A rise and fall of temperature and successive changes in appearance are two substantial sequences that occur when the material is already prepared for composting [41].

7.5.1. Rise and Fall of Temperature

Normally, a rise in the temperature is produced just after the material has been submitted to composting conditions (placed in reactor unit or windrowed). This initial rise is gradual and, then, becomes exponential arriving to 65-70ºC. This period of high temperature lasts 1-3 weeks and then temperature drops gradually reaching ambient temperature. In case composting conditions are not completely successful, this high temperature period may last more than 3 weeks (probably with lower values of 54-60ºC).

The two factors affecting rise in temperature are: heat generation by microbes and the capacity of the composting mass to retain heat.

Temperature rise is an indicator of microbial activity as respirational activities of this microbial population generate heat. Microbes do not used all the chemical energy present on the substrate and, the unused energy becomes heat. Thus, the higher the microbial activity, the greater is the rate of heat released.

The exponential rise in temperature coincides with the moment in which the breakdown of the readily decomposable material (starch, sugars, simple proteins) is being carried out. Consequently, in this period, the microbial populations increase exponentially in number.

Afterwards, as the easily decomposable components of the waste have been already composted, microbial activity decreases and subsequently the temperature drops. Temperature reaching ambient values can be understood as stable compost ready for storage or utilization because the more biologically unstable compounds in the composting mass have been stabilized.

7.5.2. Changes in Appearance

An important fact that determines if the composting process is being well conducted is a change on the appearance of the initial raw material waste that acquires a darker tone. At the end of the process, the waste has evolved from dark grey to brown color.

According to texture, the decomposition, abrasion, and maceration result in a diminution of the particle size. In addition, amorphous material gains a granular aspect and fibers have a tendency to become fragile.

Another significant modification is the change in odor. It will depend on how well the process is progressing. Few days after the first stage, the initial odor of the raw waste turns into an accumulation of odors ranging from a moderate cooking odor in the best case to an odoriferous putrefying flesh in the worst case. Mostly if pH value is high (above 7.5) and C:N ratio is low, these odors may be combined with ammonia smell. Finally, all the possible odors generated disappear or are replaced by an odor characteristic of freshly turned loam.

7.5.3. Chemical Changes

This change refers to a modification in molecular structure where the concentration of organic matter decreases while the stability rises. Compared to the mentioned changes, this chemical change is not perceptible to our senses. During the biological decomposition, the organic matter containing carbon is converted into carbon oxide. In the composting process complex substances are reduced to simpler forms. Among the existing complex molecules in the process, the ones subjected to biological decomposition (biodegradables) are transformed into simpler molecules. On the other hand, partly or completely unbiodegradable molecules have a tendency to remain unmodified. Therefore, the aim during composting consists in increasing the stability of the material by losing or reducing the decompostable mass into simple forms and by maintaining unaltered the non biodegradable molecules.

7.5.4. Indicators

In regard to all the above information, four useful indicators can be defined to control and monitor the course of the compost process [35]. They are:

1. Temperature rise and fall
2. Change in appearance and odor
3. Change in texture
4. Destruction of volatile solids

In the case of composting material that contains great percentage of inert compounds, the intensity of the four indicators may be decreased.

Taking into account the temperature rise and fall, if the temperature of the waste does not begin to rise quickly within 1-3 or 4 days, something essential is missing. A common reason is an excess or lack of moisture. The appearance of malodors is caused by excess of moisture. On the contrary, no odor means that the material is too dry. An alternative cause might be an extremely high C:N although this situation normally provoke some increase in temperature. An inappropriate pH can also be the cause.

If the moisture is too high, aeration should be increased in order to decrease the level of moisture by evaporation. Otherwise, a bulking material can also be added. On the opposite situation, in case of too little moisture, water is required.

A problem of high C:N can be solved by introducing a highly nitrogenous waste such as animal manure or sewage sludge. A low pH can be raised by addition of lime.

A noticeable alteration in some of the previous mentioned parameters during the course of composting process manifests problems. Thus, a serious problem appears if temperature drops significantly when it is supposed to be raising exponentially. In a mechanical system, this event might be due to inadequate aeration equipment. In a windrow, the cause might be excessive moisture and, therefore, aeration by turning seems to be the best solution. If the declination persists incorrect aeration or deficient moisture is the origin.

Taking into account odors, it can be said that the olfactory sense is a great device for monitoring level of aeration. Odors remaining invariably are symptoms of an anaerobic process produced by insufficient aeration or too much moisture content. If that is the case, more oxygen needs to be supplied considering an adequate air distribution throughout the pile.

To conclude, the persistence of temperature declination even after having provided proper conditions signifies that the process is coming to an end and that the composting material is gaining stability. Therefore, the composting mass can be considered suitably stable when temperature approaches ambient temperature.

8. Management of the Sludge from Wastewater Treatment Plant

Chrome tanning is performed in Sheba Leather Industry and it results in a large amount of chrome-containing solid waste categorized as toxic and hazardous. Therefore, the release of this heavy metal as waste creates a significant environmental problem and its concentration in the effluent must be lowered to permissible limits before discharging into the surface water.

In addition, during the wastewater treatment another waste is generated: sludge. It also contains chromium and other hazardous metals. An example of the characterization of the sludge from a wastewater treatment plant in Igualada (IDR) is illustrated in *Table 8.1*. From that data it can be observed that the content of chromium is much higher than the permissible content in soils, which is 100-150 ppm [7].

In case of Sheba Leather Industry, at this moment the sludge is being disposed into the landfill without any previous treatment and, consequently, is affecting negatively the environment. Even it is difficult to obtain benefits from this toxic sludge, it is possible to reduce the amount of it and improve its characteristics before disposing it in the landfill. A visit to the composting plant of Jorba (Barcelona) was conducted in order to have a better understanding of the methodology followed in the composting of this type of materials. From that visit it was recognized the possibility of composting the sludge with crushed wood.

RESULTADO DEL INFORME ANALÍTICO:

Determinación	*Unidades*	*Resultado*	*Metodología*
pH (*)	unid. pH	6.76	PNT LAB 04
Conductividad a 25 °C (*)	μs/cm	3000	PNT LAB 5
Nitrogeno amoniacal (*)	%	0.79	PNT LAB 30
Pérdida a 105°C	%	76	PNT LAB RES 01
Pérdida a 500 °C-105 °C	%	76	PNT LAB RES 02
Nitrógeno total Kjeldahl (*)	%	5.9	PNT LAB 77
Relación C/N (*)		6.4	PNT LAB 35
Fósforo extraíble en agua regia (*)	mg/Kg	6660	PNT LAB 07
Potasio extraíble en agua regia (*)	mg/Kg	1710	PNT LAB 07
Sodio extraíble en agua regia (*)	mg/Kg	7410	PNT LAB 07
Hierro extraíble en agua regia (*)	mg/Kg	16300	PNT LAB 07
Calcio extraíble en agua regia (*)	mg/Kg	34300	PNT LAB 07
Magnesio extraíble en agua regia (*)	mg/Kg	2690	PNT LAB 07
Mercurio extraíble en agua regia (*)	mg/Kg	< 0.25	PNT LAB 07
Cadmio extraíble en agua regia (*)	mg/Kg	5.5	PNT LAB RES 09
Cobre extraíble en agua regia (*)	mg/Kg	262	PNT LAB RES 09
Cromo extraíble en agua regia (*)	mg/Kg	13900	PNT LAB RES 09
Níquel extraíble en agua regia (*)	mg/Kg	32	PNT LAB RES 09

Barcelona, 6 de marzo de 2015

Table 8.1: Screening Report of the Sludge from IDR Waste Water Treatment Plant in Barcelona

The procedure that needs to be taken into account was explained in the composting plant of Jorba and is exposed as follows:

The principal aim of composting sludge from tanneries with crushed wood is based on reducing as much as possible the moisture of the sludge to generate dry sludge and reduce significantly its weigh. The moisture content can be reduced a 70%; i.e., from the initial 100 T of sludge that enter the composting plant only 30 T will be disposed in the landfill. The materials are mixed in a ratio of 3:1 in terms of m^3 (crushed wood:sludge) and approximately 80% of the crushed wood can be reused at the end of the process. The size of the crushed wood needs to be enough to allow aeration (see *Figure 8:1*.).

Figure 8.1: Crushed wood used as composting material. Its size is suitable to permit correct aeration.

The composting method consists in windrow composting with piles of great dimension (i.e., 18 m wide, 2.5-3 m high and up to 80 m long) that need to be turned periodically during the process and ultimately sifted. The mixture does not need to be hydrated, as the objective is to dry it. Therefore, no leachates are generated. The process lasts about 8 weeks and during its performance the appearance of the composting material changes as shown in *Figure 8.2*. Finally, the sifted compost can be disposed in a secure landfill.

As mentioned above, the sludge is considered a hazardous material and some cautions needs to be considered. The terrain in which the windrows are piled needs to be a paved area with a ceiling to avoid damages because of the rain. Moreover, it might be a rainwater collection system to avoid the contamination of the surrounding area due to trace elements of chromium that could carry the water.

Figure 8.2: On left side: appearance of a windrow containing sludge and crushed wood. On right side: sifted compost ready to be brought to the landfill.

9. State of the Art

From literature it was been found that over the years tanneries have been suggesting and performing different solid waste management practices in order to reduce the negative environmental impact that the waste originates. Tanneries are looking forward to recycle or reuse their waste for other purposes.

The following *Table 9.1* shows a proposal of possible treatments technologies for the tannery wastes depending on its nature.

Wastes	Treatment technology and utilization
Salt	Reuse and recycling
Hairs	Composting, direct use in soil (agricultural recycling)
Fleshings	Composting, soap manufacturing, flours for animal feed, gelatin and collagen production
Pickled hide trimmings	Gelatin production
Liming hide trimmings	Composting, gelatin production, dog bones and flours for animal feed production
Wet-blue leather shavings	Fertilizer production, agglomerate leather manufacturing (leatherboard)
Wet-white leather shavings	Composting, glue production
Wet-blue trimmings	Fertilizer production
Vegetal-tanned leather trimmings	Composting, reused in leather artifacts production, exported, agglomerate leather (leatherboard) , glue production
Semi finished leather trimmings	Fertilizer production, agglomerated leather (leatherboard)
Finished leather trimmings	Fertilizer production
Buffing dust of finishings	Fertilizer production, blends for co-processing

Table 9.1: Residues and wastes from tannery, their utilization options [42].

From the *Table 9.1* it can be seen that even part of the wastes are still being disposed in landfills, other wastes such as hairs, fleshings, raw trimmings, vegetal tanned hides trimmings and wet-white leather shavings, are principally destined to composting or applied directly to the soil (agricultural recycling). Also the wastes are reused in the production of gelatin, soap, dog bones and flours to animal feed production. The fleshings can also be used in oil extraction (olein), and the green hide cuttings, in collagen production. The wet-white shavings can also be destined to glue production [42].

The hazardous wastes containing chrome such as shavings, wet-blue trimmings, crust and finished trimmings, and buffing dust, are still destined to secure landfills. Some of them can be used in agglomerate leather manufacturing or destined to a company that used this material in fertilizer production.

In case of the sludge, it can be divided in two groups: hazardous sludge containing chrome and sludge free of chrome.

The first mentioned containing chrome sludge has not an application and has to be disposed in a secure landfill. However, it is recommended to compost the hazardous sludge as mentioned in *section 8* in order to reduce its weight before disposing it.

On the other hand, the sludge non-containing chrome can be destined to composting or agricultural use. Moreover, it can be used as blends for co-processing [42].

Wastes	**Treatment technology and utilization**
Sludge containing chrome from wastewater treatment plant	Secure landfill (previous composting)
Sludge non-containing chrome from wastewater treatment plant	Agricultural use, composting, blends for co-processing

Table 9.2: Treatment technology and utilization for the sludge [42].

It can be observed that currently tanneries are acting to face with their negative environmental impact. However, a large part of the wastes are destined to landfills. Therefore, further research needs to be done to improve the reuse or recycling of wastes and wastewater from tanneries.

10. Results

10.1. Tannery Solid Waste Analysis

In order to guarantee a satisfactory waste management plan it is imperative to have a good knowledge of the waste's generators, its generation rates and its physical and chemical characteristics.

10.1.1. Types and Sources of Tannery Solid Waste

A visit through all the leather operational processes of Sheba Leather Factory was conducted in order to determine the physical composition of the tannery solid waste generated. The observations were made at two units of the tannery (hides and skins unit) and the wastes that were identified by physical observation were: shacked salt, raw trimmings, fleshings, hair waste, splitting waste, shavings, crust and leather trimmings. In addition, during the wastewater treatment other solid waste, sludge, is produced. Some of them are shown in *Figure 10.1* below.

Raw trimmings *Hair waste*

Fleshings *Chrome shavings and trimmings*

Splittings *Crust trimmings*

Figure 10.1: Types of Solid Waste

The main sources of these solid wastes were found to be trimming, un-hairing and fleshing, which are all performed in beamhouse, splitting, and chrome shaving after chrome tanning, crust trimmings after re-tanning, leather trimmings after finishing process, and sludge after the tannery wastewater treatment.

10.1.2. Generation Rate

10.1.2.1. Weigh Procedures

Aiming to determine the weight of a single piece of wet salted hide or skin, different batches prepared for soaking operation were selected randomly. The hides/skins within each batch were weighed and an average weight was defined.

As a result, the average weight of a piece of wet salted hide was assumed to be 15 kg. In case of sheep skin, 1.5 kg, and for a single piece of goat skin, 1.4 kg.

On the other hand, it was imperative to determinate the generation rate of tannery solid waste per kilogram of raw hide or skin processed at every different leather operation. With that purpose, ten pieces of hide/skin were randomly taken and weighted before and after the studied operation to calculate the solid waste generated on the selected process. This procedure was carried out in every unit operation of leather manufacturing process that was expected to generate solid waste.

The data obtained is compiled in *Table 10.1, 10.2 and 10.3*.

Solid waste generated per day for 600 pieces of Raw hide				
S/N	**Type of waste**	**Weight [kg]**	**Generation rate [kg / kg of wet salted hide]**	**Generation rate [kg/tonne of wet salted hide]**
1	Shacked salt	144	0.0160	16
2	Fleshings and Trimmings	3,780	0.4200	420
3	Unusable splits	1,466.8	0.1630	162.97
4	Wet trimmings (after sammying)	750	0.0833	83.33
5	Shavings	2,297.34	0.2553	255.26
6	Trimmings (Dry)	55.8	0.0062	6.20
7	Sludge	4,255.20	0.4728	472.80
	TOTAL (including sludge)	**12,749.14**	**1.4166**	**1,416.57**
	TOTAL (non including sludge)	**8,493.94**	**0.9438**	**943.77**

Table 10.1: Daily Generation Rate of Solid Wastes in case of Hides

ETSEIB

Solid waste generated per day for 2000 pieces of Sheep Skin				
S/N	**Type of waste**	**Weight [kg]**	**Generation rate [kg / kg of sheep skin]**	**Generation rate [kg/tonne of sheep skin]**
1	Raw Trimmings	275	0.0917	91.67
2	Shacked salt	39	0.0130	13
3	De-wooled hair	958	0.3193	319.33
5	Fleshings	1,160	0.3867	386.67
6	Wet Trimmings	150	0.0500	50
7	Trimmings(Dry)	16.25	0.0054	5.42
8	Buffing dust	8.53	0.0028	2.84
9	Shavings	38.25	0.01275	12.75
10	Off-cuts	13.03	0.0043	4.34
TOTAL		**2,658.06**	**0.8860**	**886.02**

Table 10.2: Daily Generation Rate of Solid Wastes in case of Sheep Skins

Solid waste generated per day for 4000 pieces of Goat Skin				
S/N	**Type of waste**	**Weight [kg]**	**Generation rate [kg / kg of goat skin]**	**Generation rate [kg/tonne of goat skin]**
1	Raw Trimmings	780	0.1393	139.29
2	Shacked salt	26	0.0046	4.64
4	Fleshings	2,000	0.3571	357.14
5	Wet Trimmings	108.36	0.0193	19.35
6	Trimmings (Dry)	3.27	0.0006	0.58
7	Buffing dust	0.24	4.285E-05	0.04
8	Trimmings (Dry)	14.83	0.0026	2.65
9	Buffing dust	3.67	0.0006	0.65
10	Shavings	368.33	0.0658	65.77
11	Trimmings (Dry)	6.38	0.0011	1.14
12	Buffing dust	15	0.0027	2.68
13	Shavings	141.67	0.0253	25.30
TOTAL		**3,467.76**	**0.619**	**619.24**

Table 10.3: Daily Generation Rate of Solid Wastes in case of Goat Skins

10.1.2.2. Annual Generation Rate

It can be seen from *Table 10.1* that processing one tonne of wet salted hide can generate 944 kg of solid wastes and 473 kg of sludge. The daily hide soaking capacity in Sheba tannery is 9000 kg and, as the factory has 275 working days per year, the annual soaking capacity is 2,475 tonnes of hide. Consequently, 2,336 tonne of solid waste is generated annually during the overall tannery hide operations (from beamhouse to finishing processes). In addition, 1,170 tonnes of sludge are annually generated from tannery wastewater treatment plant.

As represented in *Table 10.2*, regarding sheep skins, processing one tonne of sheep skin can generate 886 kg of solid wastes. The daily sheep skin soaking capacity is 3,000 kg, and the annual soaking capacity is 825 tonnes of hide. As a consequence, 731 tonne of solid waste is generated annually during the overall tannery sheep skin operations.

Finally, *Table 10.3* shows the case of goat skins in which processing one tonne of goat skin can generate 619 kg of solid wastes. The daily goat skin soaking capacity is 5,600 kg, and the annual soaking capacity is 1,540 tonnes of hide. Therefore, 953 tonne of solid waste is generated annually during the overall tannery goat skin operations.

Therefore, including the sludge, a total of 5,190 tonnes of solid waste is generated annually by the company. At that moment, the overall solid wastes generated are disposed to an open dumping area on the surrounding of the industry without receiving any previous treatment.

10.1.3. Physico-chemical Characteristics

A complete physicochemical analysis of the wastes should determine the following parameters: pH, moisture content, volatile organic compound, ash content, carbon content, nitrogen content, calorific value. Taking into account the available materials in Sheba laboratory only pH and moisture content could be determined. In regard to the untested parameters, in order to have a clear idea of the estimated ranges, a search on information from other tanneries was carried out. The average values of the physicochemical parameters of a tannery solid waste from Addis Ababa (ELICO) are shown in *Table 10.4 and Table 10.5* [43].

Types of tannery solid wastes	pH	Moisture Content (%)	VOC (%)	Ash Content (%)	CV (KJ/Kg)	C (%)	N (%)	C:N Ratio
Skins Trimmings	9.85	59.00	95.60	4.40	7853	53.11	34.71	1.53:1
Hair Waste	9.90	57.00	93.11	6.89	7888	51.73	44.63	1.16:1
Fleshings	11.4	80.00	96.40	3.06	8998	53.86	13.10	4.11:1
Pickle Trimmings	3.00	65.00	87.13	12.87	7694	48.41	15.24	3.18:1
Chrome shaving	4.21	47.80	93.20	6.80	7663	51.78	63.10	0.82:1
Crust Trimmings	4.40	6. 65	91.40	8.60	17, 556	50.78	39.61	1.28:1
Leather Trimmings	4.80	9.83	97.30	2.70	18,772	54.06	48.7	1.11:1

Table 10.4: Average values of physicochemical parameters of ELICO tannery [43]

Types of tannery solid wastes	Cr (ppm)	Na (ppm)	Ca (ppm)
Skins Trimmings	Non	45,435	Non
Hair Waste	Non	11,325	Non
Fleshings	Non	44,384	12,799
Pickle Trimmings	Non	39,320	831
Chrome shaving	16,943	13,234	711
Crust Trimmings	14,821	879	787
Leather Trimmings	12,530	797	797

Table 10.5: Average Value of Chromium, Sodium and Calcium content in ELICO tannery [43]

10.1.3.1. Determination of pH

The pH of some of the solid wastes was determined by adding five grams of a sample of solid wastes in 100 ml of distilled water for 16-24 hours. After this period of time a direct measurement of the pH was carried out in accordance with the standard methods of SLC 13 [44].

10.1.3.2. Determination of Moisture Content

Moisture content refers to the mass of moisture per unit mass of wet or dry materials. Its determination was conducted by first weighting the samples of solid wastes and, afterwards, by putting them in the oven at 105ºC for 24 hours. The sample was kept in desiccators for about 30 minutes and then weighed and recorded. The effectuated calculation followed the next formula [45]:

Moisture Content (%) = ((w-d) / w) x 100

Where: w = initial mass of sample as delivered
d = mass of sample after drying

The results of the analysis made in Sheba are shown in *Table 10.6*.

S/N	Type of waste	pH	Moisture Content (%)
1	Raw trimming	7.4	25
2	Pelt trimming (after fleshing)	9.6	75
3	Fleshing waste	9.8	83
4	Sludge	8.1	7.6
5	Hair waste	8.88	62

Table 10.6: Results of the characterization analysis of solid wastes carried out in Sheba Leather Industry

ETSEIB

10.1.4. Analysis of Data Generated

10.1.4.1. pH

The pH value in case of tannery solid waste fall in a wide range from 3.0 up to 9.8. This fact demonstrates that the pH values have a great correlation with the pH values at which hides and skins are processed. For example, un-hairing and liming operations are performed in alkaline conditions and the wastes they generated have a basic pH. On the other hand, pickling and chrome tanning are carried out under acidic pH conditions as can be proved regarding the pH values of the solid wastes generated on these processes.

Great amount of the solid wastes are generated during beamhouse operations and, as are un-tanned wastes, are alkaline in nature. As most of the living organisms are susceptible to environmental pH, it should be mandatory to neutralize the solid wastes before disposing them to the environment.

10.1.4.2. Moisture Content

The moisture content ranges from 6.65% for crust trimmings to 83% for fleshings waste. Operations carried out in the beamhouse, the tanning and the re-tanning areas are performed in water. After re-tanning, the leather is dried and subsequent operations are dry processes. Therefore, fleshing and pickle trimmings wastes, which are generated during wet processing stages, show higher amounts of moisture content. Contrarily, crust trimmings and finished leather trimmings waste from dry processing stages have lower moisture content.

Taking into account the moisture content, crust trimmings and leather trimming wastes are suitable sources for thermo-chemical conversion technologies as incineration and gasification technology in order to generate energy. On the other hand, the moisture content of trimmings, fleshings, sheep hair and pickle trimmings is greater than 50%. This fact makes these wastes appropriate for bio-chemical conversion like composting method.

Considering the high moisture content of tannery solid wastes, it is of great importance to avoid the infusion of the chemicals, especially chrome, into soil, surface and ground water. Otherwise, a deterioration of the natural structures of these receiver environments will occur. Therefore, chrome shaving wastes need to be securely disposed in a landfill or, if possible, used to produce valuable products.

10.1.4.3. Volatile Organic Compound and Ash Content

The data compiled in *Table 10.4* above shows that more than 90% of the tannery solid wastes are organic wastes.

10.1.4.4. Calorific Value

The sample tannery solid wastes ranges from a minimum value of 7,694 kJ/kg, in case of pickle trimmings, to a maximum value of 18,772 kJ/kg in the case of finished leather trimmings. Therefore, the calorific value of all the solid wastes generated during the leather processing is above the minimum required value, which is 5040 kJ/kg [46], for the application of thermo-chemical conversion technologies. The suggested technology is useful for wastes containing low moisture content and, thus, solid wastes from dry processing operations such as crust and finished trimmings can be segregated to apply the mentioned technology.

10.1.4.5. Carbon and Nitrogen Content

The Carbon Content ranges from 48.41% for pickle trimmings to 56.06% for leather trimmings.
On the other hand, the Nitrogen Content ranges from 13.10% for fleshing waste to 63.10% in case of chrome shavings. The minimum value found in fleshing waste is justified because those wastes are generated by the removal of a hypodermis layer, which has great amount of fat but is poor in protein [43].

10.1.4.6. Carbon to Nitrogen Ratio (C:N ratio)

The importance of this parameter for the decomposition of solid waste carried out by the microorganisms is explained above in chapter 7, section 7.3.1.2. If it exists the interest of implementing composting method, the suitable ratio should be 25-30:1. It can be observed from *Table 10.4* that the C:N ratio of all the solid wastes is less than the required value for composting. For example, fleshings have the maximum ratio of 4.11:1 but it is still one sixth of the standard value for composting.

However, the solid wastes can be segregated and mixed with other feedstock that will help to adjust the C:N ratio value. In the study case, in order to increase the C:N, high carbon content wastes may be added. Therefore, it is possible to prepare compost from fleshings or other tannery wastes but they need to be mixed with other organic wastes.

10.1.4.7. Chromium, Sodium and Calcium Content

As shown in *Table 10.5*, raw trimmings, hair waste, fleshings and pickle trimmings were found to be non-containing chrome wastes as they are generated before chrome tanning operation. Contrarily, the highest value of chromium corresponds to chrome shavings as this waste is generated after chrome tanning process. The standard safe limit for chromium metal in soil is 100-150 ppm [7]. Therefore, the value in case of chrome shavings is much higher and this waste should be disposed in a secure landfill and not in open dumping areas.

The maximum content of sodium corresponds to raw trimmings as a result of the preservation method applied to the hides and skins in which sodium salt is used. These wastes as well as the shacked salt removed from raw hides and skins cannot be disposed to the open dumping area. The presence of common salt in soils can change their structure and cause a significant reduction of crop yields. Consequently, it would be of great interest to reuse the shacked salt for preservation instead of disposing it.

The highest value of calcium corresponds to fleshing waste due to the fact that lime is applied to the hides and skins on the preceding operation (liming).

10.1.4.8. Solid Waste Management Options

The generation rate of tannery solid waste shows that more than 60% of the solid wastes are generated during beamhouse operations. These wastes are mainly trimmings, hair and fleshings, and as they are generated from wet leather processing stages, its moisture content is high. (65% on average). Literature considers economically feasible to implement bio-chemical conversion methods. For example, it is possible to implement anaerobic digestion of the fleshings and use the digested sludge as manure. The biogas generated can be used to recover part of the energy required for tannery operations [47]. On the other hand, these biodegradable solid wastes, generated from beamhouse stages are characterized by a low carbon to nitrogen ratio. However, in addition to anaerobic digestion, composting method can be used if other carbon rich organic wastes are added to the mixture.

On the other hand, the wastes generated on dry leather processing stages such as crust and leather trimmings are characterized by low moisture content and high calorific value. The calorific value of the waste determines the amount of energy that is going to be generated at a waste to energy facility. Literature affirms that in order to facilitate the combustion of waste, the calorific value of the waste should have a minimum value of 5000 KJ/kg and approximately 6000 KJ/kg for power generation [48].

Therefore, the high calorific value of crust and leather trimmings promotes the combustion of waste with less amount of auxiliary fuel support and, as a consequence, thermochemical conversion technologies such as incineration and pyrolysis/gasification become suitable options to be applied in order to generate energy.

Lastly, the physicochemical analysis demonstrates that the chromium content of chrome shavings is much higher than the standard safe limit for soil (100-150 ppm) [7]. This metal is highly toxic and, consequently, it is of great importance to collect this waste separately and to dispose it in a secured landfill.

10.2. Materials and Methods for Composting Samples

To perform this demonstrative process, was taken into account the results of previous researches on composting and the experience of the professors of the agricultural school in Wukro (Wukro St. Mary's College).

10.2.1. Materials

The following materials were used to conduct the assay:

- 8 bins of 40 litres
- Gloves
- Tools used for cutting (scissors, grass hook)
- Weight
- Water
- Soil thermometer
- Feedstock for composting samples:
  - Tannery wastes
    - Trimmings
    - Fleshings
    - Hair
  - Organic wastes
    - Greens
    - Browns
    - Cattle manure
  - Facilitators
    - Ash
    - Soil
    - Old compost
  - Inoculums
    - EMRO® (Effective Microorganisms)
  - Vermicomposting
    - Worms *Eisenia hortensis*

As mentioned previously, composting method was selected as a suitable option to deal with the disposal of some of the solid wastes generated. It was decided to prepare different samples due to the natural variation in raw materials and in environmental conditions. When composting process finishes, these samples will be analyse to assess the proper adjust of the materials used and to proceed with full-scale composting plants.

Tannery wastes are known to have strong alkaline conditions. Consequently, it will be convenient to add some types of inoculums to these wastes in order to activate the biological transformation and facilitate the process.

Three types of wastes were selected for the composting samples: raw trimmings, fleshings and hair from sheep.

All of these solids are generated during the first steps of the leather production, before the chrome tanning is carried out and, therefore, are solids non-containing chrome. The chromium metal is highly toxic and, in large content, it is not safe to be in the soil. For that reason, only the free-chrome wastes were used for the composting samples.

10.2.2. Feedstock

10.2.2.1. Tannery wastes

Trimmings are unwanted parts removed by cutting the edge of hides and skins. The ones used correspond to the undesirable parts of the first raw hides and skins.

Fleshings are a solid waste generated during a mechanical process known as fleshing in which flesh or fats from the inner part of hide and skins are removed.

Hair waste is generated by sheep skins processing. Unlike cattle hide processing, sheep skins are subjected to a chemical process called unhairing process to remove the hair. This process is conducted just after soaking process is finished and before fleshing operation.

10.2.2.2. Organic Wastes

Browns are dry and dead plant materials including fall leaves, dried grass, paper, straw and wood products. The browns contain low level of nitrogen. They are high carbon and a source of energy for the compost microbes. This dry material can absorb excess moisture in the volatile feedstock and tend to be bulky. This helps to increase the available air space between particles in the mixture, it promotes good aeration.

Greens are fresh (and often green) plant materials such as fresh grass clippings, plant clippings, freshly picked weeds and most kitchen scraps. The greens contain high level of nitrogen but, over time, they go brown dropping the nitrogen levels. They tend to be high in moisture, and balance out the dry nature of the browns. Go to *Annex E* to see estimated C:N ratios of browns and greens.

Browns *Greens*

Figure 10.2: Browns and Greens feedstock that were used for composting samples.

Cattle manure based in colour it is a brown, but it can be considered as green in terms of content of nitrogen. It has a high content of nitrogen.

Annex E contains a list with the average C:N ratios for some common organic materials found in the compost bin.

It is important to understand that every ingredient has its own C:N ratio and it has been proved that the fastest way to produce fertile, sweet-smelling compost is to maintain a C:N ratio around 25-30:1. If the C:N ratio is too low (excess nitrogen) the pile will start having an unpleasant odour. If the C:N ratio is too high (excess carbon), decomposition will slow down.

If the C:N ratio is wrong, the microbes will not decompose the organic matter as fast and the process will take longer and will be carried out at lower temperatures but it will happen. Therefore, the right C:N ratio is not a must but it will help the process to be completed faster.

Figure 10.3: Cattle Manure that was used for composting samples

10.2.2.3. Facilitators

Ash, soil and old compost facilitate the composting process. Ash helps maintaining the neutral condition of the compost. It can also add nutrients to the soil and it is a natural source of potassium. Soil gives weight to the mixture and has organic and mineral matter.

Ash *Soil* *Old compost*

Figure 10.4: Facilitators that were used for composting samples

10.2.2.4. Inoculums

As inoculums, commercial microorganisms were chosen for this assay. The available brand was EMRO®. The quantity to be applied varies as per supplier recommendations and is dependent on the Effective Microorganisms (EM) activation system and its dilution, as well as supplier's experience.

The recommended quantity to be adjusted was 15 Litre per 1 metre cubic of composting materials [49].

Effective Microorganisms (EM) consists on a combination of several beneficial microorganisms from natural sources: phototropic bacteria, lactic acid bacteria and yeasts, mainly used as food additives [49]. EM secretes vitamins, minerals, organic acids, and antioxidants when in contact with organic matter. Antioxidants' effects increase decomposition rate of organic waste and the humus content. It also eliminates disturbing odors.

Using EM products will help to speed up the process and, moreover, will increase the number and diversity of microorganisms in the soil.

Figure 10.5: EMRO® added *to the composting samples*

10.2.2.5. Vermicomposting

Vermicomposting is the process of using worms to process organic food waste into nutrient-rich soil. Earthworms can consume practically all types of organic matter and they can eat their own body weight per day (1 kg of worms can consume 1 kg of residues every day). These species eat spoiling food wastes that become compost as they pass through the worm's body. Compost exits the worm through its' tail end. This compost, named vermicompost, is a very efficient soil amendment. Their excreta (castings) contains a great number of beneficial microbes and nutrients, and is a good plant fertilizer.

Worm castings contain 5 to 11 times more nitrogen, potassium, and phosphorous than the surrounding soil. Therefore, as can be seen in *Table 10.7*, nutrients in vermicompost are much higher than in traditional compost [50]. Secretions in the intestinal tracts of worms as well as soil passing through the earthworms increase the concentration of nutrients and facilitate the availability for plant uptake.

Table 1. Chemical Characteristics of Garden Compost and Vermicompost

Parameter*	Garden compost[1]	Vermicompost[2]
pH	7.80	6.80
EC (mmhos/cm)**	3.60	11.70
Total Kjeldahl nitrogen (%)***	0.80	1.94
Nitrate nitrogen (ppm)****	156.50	902.20
Phosphorous (%)	0.35	0.47
Potassium (%)	0.48	0.70
Calcium (%)	2.27	4.40
Sodium (%)	<0.01	0.02
Magnesium (%)	0.57	0.46
Iron (ppm)	11,690	7,563
Zinc (ppm)	128	278
Manganese (ppm)	414	475
Copper (ppm)	17	27
Boron (ppm)	25	34
Aluminum (ppm)	7,380	7,012

[1]Albuquerque sample

[2]Tijeras sample

*Units: ppm = parts per million; mmhos/cm = millimhos per centimeter

**EC = electrical conductivity in mmhos/cm; a measure of the relative salinity of soil or the amount of soluble salts it contains.

***Kjeldahl nitrogen = a measure of the total percentage of nitrogen in the sample, including that in the organic matter.

****Nitrate nitrogen = nitrogen in the sample that is immediately available for plant uptake by the roots.

Table 10.7: Comparison of Chemical Characteristics of Garden Compost and Vermicompost [50]

10.2.3. Materials' Proportions

The materials and the quantity of the samples were determined keeping in mind the difficulties that present the tannery wastes to be decomposed. As a result, the organic wastes (greens, browns and manure) and the facilitators (ash, soil and old compost) were added in larger proportions than the tannery wastes (2:1).

The first eight samples were prepared without the addition of inoculums and worms to allow the evaluation of the biodegradability of the residues by themselves.

The sample process started on November 10th, 2017. Considering that compost process lasts about three months, the final compost will be ready at the beginning of February 2018.

Materials to be composted (trimmings, fleshing and hair) were mixed with the remaining waste. The amounts of all the materials are shown in *Table 10.8* where it can be seen that samples 1 and 2 were prepared by addition of hair and trimmings, samples 3 and 4 include hair and fleshings, samples 5 and 6, hair, trimmings and fleshings, and samples 7 and 8, trimmings and fleshings.

Moreover, *Table 10.8* shows that each sample was composed by:

- 1 kg of greens
- 1 kg of browns
- 2 kg of cattle manure
- 2 kg of a soil, ash and old compost. All mixed in same proportions.
- 3 kg of tannery wastes (depending on the sample different proportions)

Therefore, 6 kg of organic wastes and facilitators were mixed with 3 kg of tannery wastes producing samples of 9 kg.

Sample	Type of solid waste	Ratio of solid waste	Waste (kg)	Browns (kg)	Greens (kg)	Cattle manure (kg)	Ash + soil + old compost (kg)
1	H+T*	1:1	3	1	1	2	2
2	H+T*	1:1	3	1	1	2	2
3	H+F*	1:1	3	1	1	2	2
4	H+F*	1:1	3	1	1	2	2
5	H+F+T*	1:1:1	3	1	1	2	2
6	H+F+T*	1:1:1	3	1	1	2	2
7	F+T*	1:1	3	1	1	2	2
8	F+T*	1:1	3	1	1	2	2

*H: hair, F: fleshing T: trimmings.

Figure 10.8: Materials' proportions used in composting samples

After following the course of these eight initial samples, some improvements actions to implement in future operational procedures were defined. Finally, it was decided to prepare two new samples taking into account the defined improvements. This second time, EMRO® and worms were used. Moreover, the size of the sample was increased up to a 1 metre cubic composting pile.

The second sampling process started on December 18th, 2017 and must be finished in mid March 2018. The procedures carried out to prepare these last samples will be explained afterwards.

10.2.4. Samples Operational Procedures

The first eight samples were prepared and controlled in Wukro St. Mary's College. After discussing with some professors, it was decided to prepare two replicas of each control sample. Instead of layering compost, all the materials used were mixed from the very beginning. This new procedure has replaced the preceding method based in layers used in the school as it diminishes the time required to carry out composting process. A proper organic mixture stimulates uniform decomposition and promotes a homogeneous end product. As composting was performed mixing the initial materials, the samples did not need to be turned.

There was not enough space allowed to use for the samples and, consequently, it was decided to prepare them in containers. In order to allow aeration, various holes were made in the bins as shown in *Figure 10.6*. Those bins had a capacity of 40 L, and therefore, a sample of 9 kg was found to be appropriate.

In addition, with the purpose of avoiding the accumulation of leachates in the inferior part of the bins, holes were also made in that part. Also, the containers were placed as shown in *Figure 10.6* in a raised-open surface and not in direct contact with the soil so that the liquids released could drain down.

Figure 10.6: On left hand the holes made to the bins can be appreciated. On right hand it can be seen the store in which the eight bins were kept and the raised-open surface in which they were situated

Sample preparation procedure:

1. Prepare all the feedstock required for the process.
2. Mixing ash, soil and old compost in same proportions.
3. Weigh the indicated amount of each composting material.
4. Cut in pieces of small size the tannery wastes.
5. Also split and cut the organic wastes.
6. Spread the different wastes in a clean plastic surface and continue splitting and mixing them as much as possible.
7. When adequately mixed, add water.
8. Enter the prepared mixture into the bin.

Figure 10.7: On left side, preparing all the required feedstock. On right side, cutting and mixing the composting materials.

Figure 10.8: On left side, cutting the greens. On right side, adding water to the mixture.

Figure 10.9: On left side, mixture of greens, browns and cattle manure. On right side, the initial appearance of a hair and fleshing sample.

The follow-up and control of the demonstration process has been performed in the following manner:

The temperature must be controlled with a soil thermometer and should not exceed 60-70ºC. Also, the moisture needs to be controlled by visual observation and touch contact. When necessary, the samples were water with spray to moisten them. A decision was taken in base of the course of the process about the need and possibility of adding Effective Microorganisms and/or worms in the future.

At the **start** the materials were chosen according to their availability and to the experience in composting of some professors. As an analytical study of the materials' nature was unfeasible, they were theoretically identified in base of other studies.

During the composting process, the temperature was daily measured. The moisture was controlled by visual observation. Possible changes in odour were detected as well as changes in appearance and volume.

At the **end** the final compost will be analytically identified. The compost test will be performed in the Ethiopian Institute of Agricultural Research Jimma Soil and Plant Analysis Laboratory of Mekele (Ethiopia) in order to evaluate the quality of the compost. The facility is accredited in accordance with the requirements of ISO/IEC 17025:2005, *General requirements for the competence of testing and calibration laboratories*.

In case the mature compost has favorable physical and chemical properties, it should enhance the growth of plants. Therefore, plant growth experiments must be done to determine if the compost can be used as a soil fertilizer.

Type of Test	Name	Properties Tested
Stability	Jar Test	odor development
	Self-Heating Test	heat production
	Respiration Test	CO_2 generation
Quality	Phytotoxicity Bioassay	effects on seed germination and root growth
Effects on soil properties	Porosity	volume of pore space
	Water Holding Capacity	ability to retain moisture
	Organic Matter Content	percent organic matter
	Buffering Capacity	ability to resist change in pH

Table 10.9: Different tests of Compost properties [51]

10.3. Analysis of Composting Results

The description of the composting samples' evolution, the results and the measurements conducted are defined in this section. The composting process is underway at this moment and, therefore, the following paragraphs just include the overall activities and measurements carried out to date. The data exposed below correspond to the eight initial weeks (from November 10^{th} up to January 4th).

10.3.1. Initial Characteristics of the Samples

As mentioned above, it was not feasible to take some of the initial materials for analysis. Therefore, a theoretical analysis of their properties was performed to appreciate the nature of the feedstock that was going to be used. The results are shown below.

The characterization of tannery solid wastes is shown in *Table 10.10:*

Solid Waste/Parameter	pH	Moisture (%)	VOC* (%)	Ash content (%)	CV* (kJ/kg)	C:N ratio
Trimmings	7.4	25	95.60	4.40	7,853	1.53:1
Fleshings	9.8	83	96.40	3.06	8,998	4.11:1
Hair	9.90	57.00	93.11	6.89	7,888	1.16:1

*VOC: Volatile Organic Compound, CV: Calorific Value

Table 10.10: Characterization of tannery solid wastes including trimmings, fleshings and hair waste [43].

The characterization of manure is based on sheep manure and shown in *Table 10.11* and the characterization of green waste is shown in *Table 10.12*. Also go to *Annex E* to see a list of the estimated C:N ratios of the organic composting materials (browns and greens).

Parameters[a]	SM
pH[b]	8.51
EC[b] (dS m^{-1})	11.33
OM (g kg^{-1})	456.5
Lignin (g kg^{-1})	211.4
Cellulose (g kg^{-1})	113.6
Hemicellulose (g kg^{-1})	109.7
T_{OC} (g kg^{-1})	251.6
T_N (g kg^{-1})	17.7
NH_4^+ (mg kg^{-1})	889
NO_3^- (mg kg^{-1})	520
T_{OC}/T_N	14.3
Fat content (g kg^{-1})	5.1
WSCH (g kg^{-1})	4.5
WSPH (g kg^{-1})	3.3
WSC (g kg^{-1})	35.4
P (g kg^{-1})	2.2
K (g kg^{-1})	16.5
Ca (g kg^{-1})	100.9
Mg (g kg^{-1})	18.7
Na (g kg^{-1})	3.9
S (g kg^{-1})	13.2
Fe (g kg^{-1})	4.1
Cu (mg kg^{-1})	51
Mn (mg kg^{-1})	226
Zn (mg kg^{-1})	185
Pb (mg kg^{-1})	12
Cr (mg kg^{-1})	19
Ni (mg kg^{-1})	25
Cd (mg kg^{-1})	nd

Table 10.11: Characterization of sheep manure [52]

Parameters	Green waste
pH	7.02 ± 0.02
Moisture (%)	40.1 ± 0.1
Total Kjeldahl nitrogen (g kg^{-1})	14.1 ± 0.05
Total organic carbon (g kg^{-1})	462.3 ± 0.3
C/N ratio	32.7 ± 4.2
Ash (g kg^{-1})	81.7 ± 0.01

Table 10.12: Characterization of green waste [53]

All the samples presented a basic pH as they come from leather operations that are performed in basic medium. The content of organic matter demonstrates that the materials have an organic component that can be stabilized for composting.

10.3.2. Temperature Profile

The temperature of the mixture was measured at three different points within each sample. The three points correspond to varying heights above the bottom part of the container: lower (1), central (2) and upper (3) part. The measurement was undertaken daily for the first 8 weeks. Go to *Annex F* to see the temperature's measures. Afterwards the temperatures are going to be measured weekly at weeks 10, 12, 14 and 16. It was tried to always make the measures at the same period of the day (about 12 am) so that the temperature differs as less as possible.

Samples behaviour depends on its composition. However, they are supposed to follow a theoretical course as the one shown in *Figure 10.11*.

Figure 10.10: The three points where the measures of temperature were undertaken.

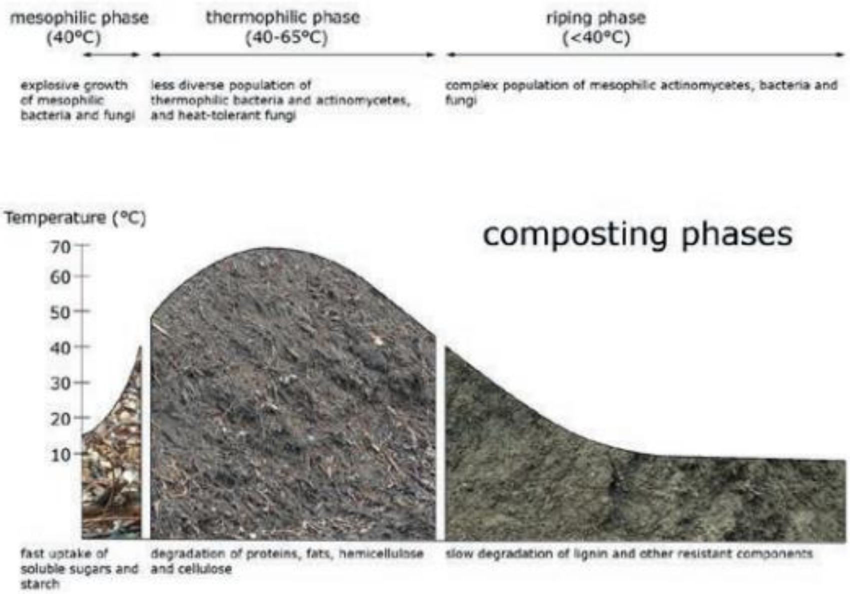

Figure 10.11: General overview of the different composting phases and the degradation processes taking place. The length of the different phases will differ according to the composting method applied.

It has to be kept in mind that is much harder to keep a small object hot than a large one because the ratio of surface area to volume goes down as volume goes up. As a consequence, in order to reach thermophile temperatures, the volume of the pile needs to be at least 1 metre cubic.

During the evaluated period the temperature presented variations between 15 and 44ºC. The temperature of the central part of the samples (point 2) was found to be slightly higher than the one in the upper and lower part, with differences of around 2ºC. this fact is due to the exposition to ambient temperature of these lasts parts.

In general the samples increased progressively their temperatures during the first two weeks up to 25ºC. However, this raise was not very significant due to the fact that the sample size was not very big. In addition, the samples were dry and no water was available. The third week water was added and, in order to facilitate the process, the available EMRO® was also added.

After that operation, temperatures continue increasing for the next days until the end of the fourth week due to an important drop of the ambient temperature. With the objective of promoting the termophilic phase the samples were exposed during the day to the sun, and they were water more often. Temperature increases up to about 40ºC determining the termophilic stage at weeks 6-7. Then, the next week the temperatures decreased gradually down to 25ºC starting the cooling stage.

The temperature is going to be controlled weekly until 16th week and the samples are supposed to decrease its temperature to ambient temperature by that time.

In the termophilic phase the temperatures did not raise to values as high as expected. The reasons are the small volume of the sample and the unusual low ambient temperature. Even though, the appearance of the mixture justifies that the decomposition of the materials is been carried out.

Figure 10.12 shows the evolution of the temperature for hair and trimmings samples. As can be observed the initial temperature of the process was 16-17ºC. During the first three weeks the temperature increased moderately. The slow raise of the temperature was due to the fact that the samples were dry and no water was provided. The third week (November 24th) the samples were hydrated and the temperature increased up to 31ºC. In these samples, no Effective Microorganisms was added. The temperatures decreased on week 5 due to the low ambient temperature and started increasing again up to 35ºC determining the termophilic stage on week 6. The next two weeks the temperature started decreasing progressively.

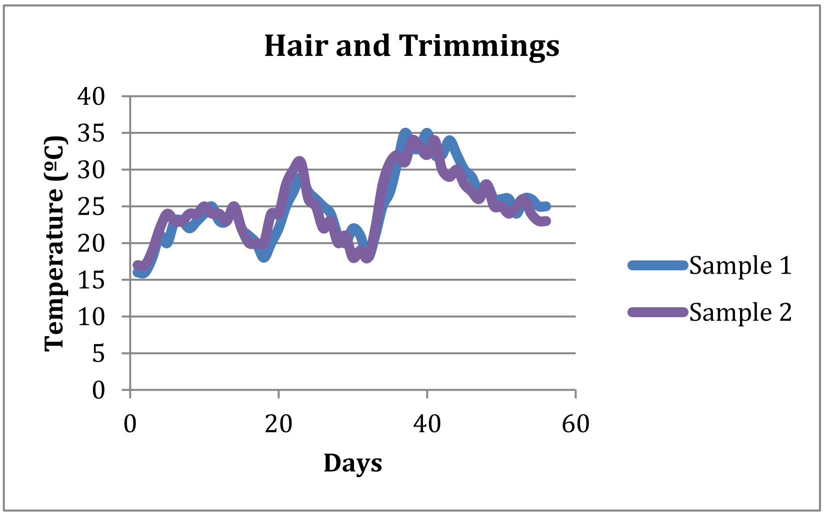

Figure 10.12: Evolution of the Temperature in Hair and Trimmings samples (samples 1 and 2)

Figure 10.13 shows the evolution of the temperature for samples of hair and fleshings. As can be observed the initial temperature of the process was 17-18°C. During the first weeks the temperature increased gradually, identifying the mesophilic stage, to under 27°C. The samples were dry and no water was available until the third week (November 24th). This day the samples were hydrated and EMRO® was added to facilitate the process. Due to the effect of EM the samples started increasing their temperature (except on week 5 because of climate adversities). They reached temperatures of 45ºC in the termophilic stage by week 6, and then, the temperature started decreasing progressively.

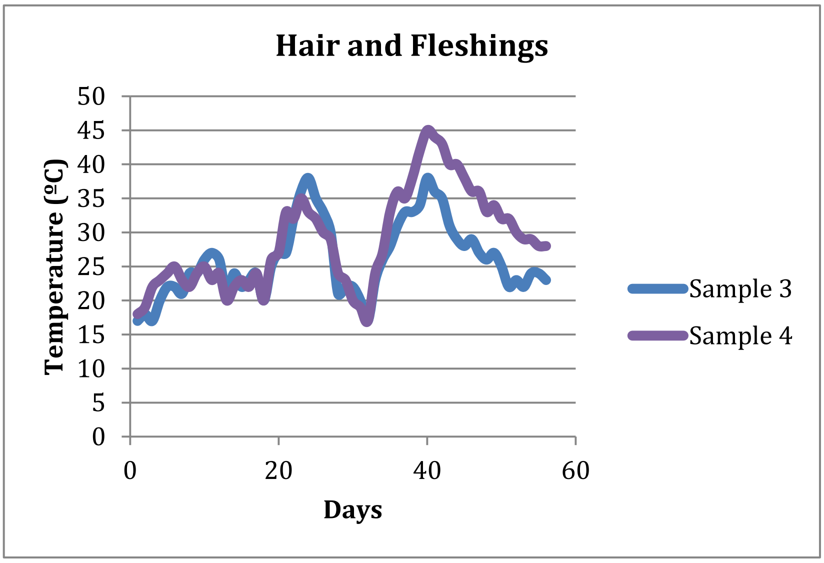

Figure 10.13: Evolution of the Temperature in Hair and Fleshings samples (samples 3 and 4)

Figure 10.14 shows the evolution of the temperature for hair, fleshings and trimmings samples. As can be observed the initial temperature of the process was 18-19ºC. During the first three weeks the temperature increased moderately. The slow raise of the temperature was due to the fact that the samples were dry and no water was available. The third week (November 24th) the samples were hydrated and EMRO® was added. As a result, the temperature increased, and reached 36ºC and 38ºC in samples 5 and 6, respectively. The temperatures decreased on week 5 due to the low ambient temperature. Then, started increasing again determining the termophilic stage up to 43ºC and 42ºC, respectively, on week 6. The next two weeks the temperature started decreasing progressively.

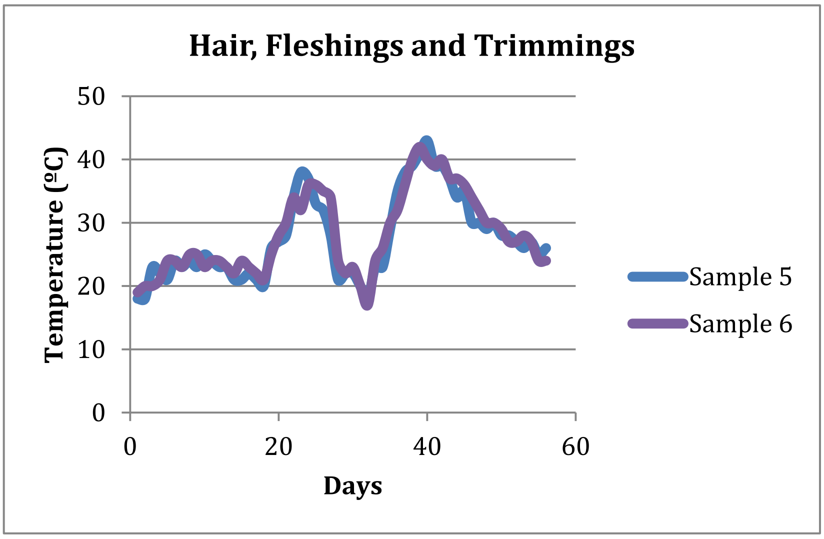

Figure 10.14: Evolution of the Temperature in Hair, Fleshings and Trimmings samples (samples 5 and 6)

Figure 10.15 shows the evolution of the temperature for samples of fleshings and trimmings. As can be observed the initial temperature of the process was 15-16°C. During the first weeks the temperature increased gradually, identifying the mesophilic stage, to under 29°C. The samples were dry and no water was available until the third week (November 24th). This day the samples were hydrated and EMRO® was added to facilitate the process. The effect of EM was observed as an increase of the temperature the next days (except on week 5 because of climate adversities). In the termophilic stage, by week 6, the samples reached temperatures of 44ºC and 39ºC for samples 7 and 8, respectively. Then, the temperature started decreasing progressively.

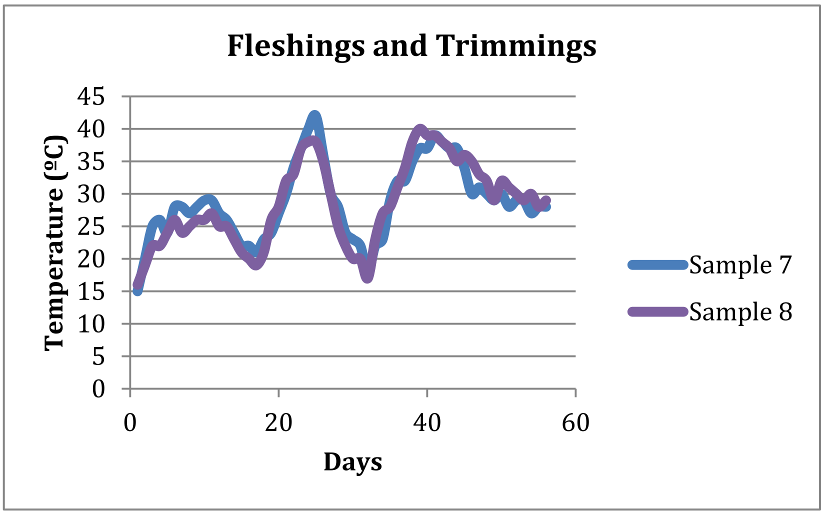

Figure 10.15: Evolution of the Temperature in Fleshings and Trimmings samples (samples 7 and 8)

Only the first eight weeks of the process have been evaluated and described, as the composting process has not already finished. Despite this fact, the known results show that it is been well conducted and that the materials are decomposing. The samples that decompose less easily were found to be the ones composed by hair and trimmings.

10.3.3. Moisture Content

Moisture content was visually and physically determined. The surface of the mixture tended to dry. During the first three weeks water was not available on the facility and, at the beginning of the third week, the samples were dry. Water was provided at the end of week 3 and the samples were hydrated.

On week 5, it was decided to expose the samples to the sun during the day as the ambient temperature dropped and the room in which they were stored was too cold. Consequently, to avoid the samples drying because of sun direct exposition, water was sprayed every 2-3 days.

10.3.4. Odor and Appearance Evolution

An important fact that can determine if the process is being well performed is a change on the odor and appearance of the initial raw material waste.

In the study case, in general, the odor and appearance of the samples were modified as the composting process moved forward.

The color turned darker and the composting materials from tannery became fragile. A volume reduction was not significant during the evaluated weeks.

A change in odor was perceived. The initial bad odor that characterized the raw materials decreased especially in the case of samples 3, 4, 7 and 8. On samples 1 and 6 the bad odor persisted longer, thus, they were turned to allow a better aeration.

10.3.5. Optimizing the Composting Process

Regarding all the above information, in order to enhance the composting process, it was considered advisable to prepare two new samples optimizing the initial operational procedures. Moreover, for that second samples, Effective Microorganisms was added from the very beginning and the vermicomposting technology was taken into account.

The second samples preparation was performed on December 18th, 2017 at Sheba Leather Industry. All the knowledge acquired from the first sampling carried out at St. Mary School of Wukro was transferred to the laboratory chemists from the factory. These employees are the ones that are going to follow the evolution of the new samples as well as proceed with the proposal of the composting method as a waste management practice to be implemented in the company in the future.

Figure 10.16: Transferring the knowledge acquired to the chemists of Sheba Leather Industry

The characteristics of the two new piles are shown in *Table 10.13.* The density of the piles was assumed as 500 Kg/m^3.

Pile	Type of solid waste	Ratio of solid waste	Waste (kg)	Browns (kg)	Greens (kg)	Cattle manure (kg)	Ash + soil + old compost (kg)	EM: *EMRO®* (L)	Worms: *Eisenia hortensis* (kg)
1	F+T*	3:1	170	57	57	110	110	15	4.88
2	F+T*	3:1	170	57	57	110	110	-	-

*F: fleshing T: trimmings.

Table 10.13: Materials' proportions used in composting piles

The main variations respect the initial operational procedures that were proposed are summarized as follows:

- The size of the particles of the composting materials was reduced to increase the amount of surface area that the microorganisms have available to act. This action enhances the decomposition rate, facilitates effective mixing and promotes a more uniform end product. It was important to keep in mind that if particles are excessively small, the material may become too dense worsening the aeration. Researchers have found that a range of particles sizes from 1.3 to 5 cm provides best balance [54].

Figure 10.17: The reduced size of fleshings (on left) and trimmings (in right).

- From the first samples it was observed that the hair waste was very hard to decompose. The other materials turned fragile while the structure of the hair almost remained the same. Consequently, on the second sampling, only fleshing and trimming waste was used as composting materials and the hair waste was declined. Moreover, the proportion of the waste also changed and it was adjusted to the generation rate of the wastes. The daily generation of fleshings is about 6 tonnes and, in the case of trimmings, 2 tonnes. As a result, the ratio fleshing:trimming waste used was 3:1.

- Sheba Leather Industry conceded a specific area among their compounds to prepare the composting piles. This second time the size of the samples was increased due to the fact that enough space was provided. The volume of the piles was 1 metre cubic (1 m length x 1 m width x 1 m height), which was found to be the minimum volume required in order to satisfy the thermophile phase.

- In the first sampling the temperature did not raise significantly the first days. For that reason, the second time not only the volume of the samples was increased but also EMRO® was added to the mixture from the very beginning, when the samples were prepared. On this occasion, as enough EM was provided, 15 L could be added to Pile 1. EM is expected to speed up the process and improve the quality of the final compost contributing in an increase in the number and diversity of microorganisms in the soil.

- In the first sampling, the containers were placed in a room all the time during the first five weeks. The ambient temperature was low and it made difficult the increase of temperatures. For that reason, after week 5 they were exposed to the sun during the day and kept in the room at night. This second time, the samples were placed outside in an area partially covered by trees to provide shadow. Therefore, the piles were moderately exposed to the sun and need to be hydrated once a week.

- During the first composting process, the presence of worms among the composting materials could be observed. Therefore, it was revealed that those species could keep alive on the tested materials and that vermicomposting could be applied. The available worms in St. Mary School of Wukro were Eisenia hortensis and the common rate that they used on their composting piles was 4.88 kg of worms per m^3 [55]. Taking into account this rate, Pile 1 of 1 metre cubic that weight about 500 kg needed 4.88 kg of worms.

  The worms could not be added the first day; it was advisable to wait 5 to 10 days so that the decomposition had started. Proceeding this way, one week after the second samples were prepared (25^{th} of December) 4.88 kg of worms were introduced only to Pile 1. They were simply scattered over the top of the bin. The skin on the worm reacts to light and, consequently, they immediately worked their way down into the mixture to get away from the light. In order to allow the absence of light the pile was covered with a plastic bag. Moreover, as vegetable and fruit wastes are adequate food for them, a little amount of these wastes was added at the same time with the worms.

These were the modifications implemented on the second sample operational procedure. The two piles are at that time under control by chemists from Sheba Leather Industry. As commented, in case of Pile 1, the composting process has been promoted with the aid of EM and worms. These beneficial elements were not added to Pile 2.
The results will be discussed in order to define the final composting operational procedure that is going to be implemented in the industry in prospect as a waste management practice.

10.4. Basic Design of the Composting Plant

If the results are optimal the composting method can be implemented as a solid waste practice in the industry. The required area for composting piles was calculated in base of the generation rate of the tannery solid waste.

The composting materials from tannery that will be used are fleshings and trimmings. The hair waste will not be used, as it does not decompose properly. The daily generation rate from hides and skins is compiled in *Table 10.14* below.

	Fleshings (kg)	Trimmings (kg)
Raw hide	2,650	1,130
Sheep skin	1,160	275
Goat skin	2,000	780
TOTAL	5,810	2,185

Table 10.14: Daily Generation Rate of the Solid Wastes used for composting

Therefore, a total of 7,995 kg of tannery solid wastes to be composed are daily generated.

The following calculations were developed in order to determinate the required area and facilities assigned to manage the overall amount of waste.

Considering that the daily generation rate of waste from tannery is 8 tonnes, the composting plant should be prepared to manage a total of 24 tonnes per day:

- 8 tonnes of tannery wastes
- 2,7 tonnes of browns
- 2,7 tonnes of greens
- 5,3 tonnes of cattle manure
- 5,3 tonnes of ash, soil and old compost

As this is a considerable amount of waste, in order to decrease the area required for the composting piles it will be assumed that the composting plant receives the wastes from the tannery every three days. This hypothesis defines an amount of 72 tonnes of total waste to be treated every three days.

The process begins with the reception of all the wastes. Then, they are mixed and placed in the composting area forming piles. Each pile is hydrated and turned periodically using a specific machine. The composting process lasts 3 months; i.e. 12 weeks.

10.4.1. Description and Calculations of the Reception/Mixing Unit

There must be an available area in which the wastes can be stored and mixed before they enter the composting process. The area of the reception unit used to accumulate and mix each of the wastes does not have to be of great dimensions taking into account that the wastes are piled up. Considering that the density of the overall wastes is 500 kg/m^3, if 72 tonnes are received every 3 days, a minimum mixing unit of 144 m^3 is required.

The mixing unit will be based on a rectangular area of:

- 2 metres height
- 5 metres width
- 15 metres length

As a result the required area is of 75 m^2.

10.4.2. Description and Calculations of the Piles Unit

Aerated or turned windrow is the selected composting method due to the low complexity as well as its low cost. This technique is suited for large volumes of waste and is based on organic waste disposed in rows of long piles called ‘windrows’. They need to be aerated periodically by either manually or mechanically turning the piles and, moreover, water as recommended for this composting method.

After visiting the Composting Plant of Jorba and studying their methodology, it has been considered the option of making piles of great dimensions. The size of the pile can be up to 3 metres of height, 20 metres of width and 100 metres of length as explained in the mentioned plant. This size pile is sufficient to generate enough heat and maintain temperatures. On the other hand, it is small enough to allow aeration flow to the windrow’s core if it is turned appropriately.

Each pile contains the mentioned wastes in the following proportions:

- 33% of tannery wastes
  - 67% of fleshings
  - 33% of trimmings
- 45% of organic wastes
  - 25% of browns
  - 25% of greens
  - 50% of cattle manure
- 22% of facilitators (ash, soil and old compost)

As mentioned before, every 3 days, 24 tonnes of tannery wastes, 32 tonnes of organic wastes, and 16 tonnes of facilitators are received in the composting plant. Therefore, a total of 72 tonnes (144 m^3) need to be managed every 3 days.

Following the recommendations of the employees from the Composting Plant of Jorba, it has been decided to generate a unique windrow of great dimensions. Every three days, the volume of waste that arrives to the plant (144 m^3) will be added to the pile. Considering that the estimated composting time is of 12 weeks (84 days), in this period there will be a total of 28 entrances of waste. As a result, the entire volume of the windrow will be 4,032 m^3 (144 m^3 x 84 days).

The structure of the pile corresponds to a pyramid of rectangular trunk whose volume can be calculated from the following *Equation 1*:

$$V = \frac{h}{3} \cdot (M + m + \sqrt{M \cdot m}) \qquad \textit{Eq.1 [56]}$$

Where:
- V: total volume of the pile
- h: height of the pile

- M: major base
- m: minor base

The total volume refers to the space that is occupied by each of the wastes in base of the density. The following parameters are adjusted as expressed below.

- Volume: 4,032 m^3
- Height: 3 m
- Major base: (18 · L) m
- Minor base: (12 · L) m

The equation changes to:

$$V = \frac{h}{3} \cdot (18 \cdot \mathrm{L} + 12 \cdot \mathrm{L} + \sqrt{18 \cdot \mathrm{L} \cdot 12 \cdot \mathrm{L}}) \qquad \textit{Eq.2}$$

Where L = length of the pile

Therefore, the length of the pile can be determined with a value of 90.21 m. Depending on the available terrain, the piles unit will be formed by a unique pile of 4,032 m^3 of volume (dimensions: 90.21 m of length x 18 m of width x 3 m of height) or the volume will be divided in two piles of 2,016 m^3 each (dimensions: 45.11 m of length x 18 m of width x 3 m of height).

Regarding the pile's dimensions, the composting pile unit occupies a minimum extension of 1,623.78 m^2. This area will be increased regarding the case of an increment of the supply feedstock as well as to provide space to store the machinery and the sifted compost. As a result, the final extension of the composting unit is 2,000 m^2 (100 m of length x 20 m of width).

This area will have an inclination of 10% to promote the collection of leachates.

The selected area has to be paved and cover with a ceiling in order to avoid the damage of the composting process because of rainwater.

10.4.3. Other Units

The composting plant will also have a site office and a leachate collection deposit. The site office will be located next to the reception unit in an available area of 25 m^2. On the other hand, the leachate collection is based on a deposit of 1,000 m^3 (dimensions: 20 m x 20 m x 2.5 m) that need to be emptied every 12 weeks.

In order to calculate the deposit dimensions it has been considered approximately a value of 5% (m^3 of leachates/T of composting waste) [57].

In 12 weeks there are 28 entrances of 72 tonnes of wastes and the composting material is hydrated once a week only during the first 8 weeks of the process. As a result:

$$Volume\ leachate\ deposit\ (m^3) = 28 \cdot 72\ T \cdot 0.05 \frac{m^3}{T} \cdot 8\ weeks = 806.4\ m^3 \qquad \textit{Eq.3}$$

10.4.4. Required Machinery

It exists a wide range of machines that can be used during the composting process. In order to select the appropriate equipment, it has been taken into account the current situation and the available resources. Therefore, the economic aspect and the level of operational difficulty had been considered. As a result, regarding the necessary operations, the selected machinery is described as follows.

10.4.4.1. Wheel Loader

It exists the option of turning the compost piles simply by first loading and then emptying the compost using a wheel loader. The operator needs to manipulate the tractor assuring that the overall material of the pile has been turned. Moreover, a wheel loader can also be used to prepare the initial mixture of the composting materials.
This was considered an advantageous option mostly because of its low investment cost and the ease of finding this common model in the market. A wheel loader can be found from 30,000 €. On the other hand, the final compost obtained with this technology has less quality and less homogeneous appearance. Also, the mature phase increases.

Considering the amount of waste that has to be treated at the composting plant, an appropriate wheel loader should satisfy the following characteristics defined in *Table 10.15* as recommended by the professionals in the Composting Plant of Jorba.

Machine	Bucket Capacity (m^3)	Operating Weight (kg)	Turning Capacity (m^3/h)	Gasoil Consume (L/h)	PRICE (€)
Wheel loader	5	12,000	200	10	30,000-60,000

Table 10.15: Specifications of an appropriate wheel loader for the case study composting plant

Figure 10.18: Wheel loaders used during the composting process [58].

10.4.4.2. Trommel Screen

The mature compost needs to be sifted in order to have an homogeneous and spongy appearance as well as an appropriate particulate size depending on its final application.

The thickest materials, which are more resilient to be decomposed, can be re-circulated. For the known amount of wastes a small screen that can sift 25 m^3/h will be enough. It will consume 4 litres of gasoil/h and its approximate cost is 50,000 €.

Figure 10.19: Trommel Screen used to obtain sifted compost [59]

10.4.5. Description of the Operational Procedure

As described above, a total pile of 4,032 m^3 is generated and 144 m^3 of wastes are added every three days. The composting materials that are part of the windrow are in different stages of the composting process. The ones at the beginning of the pile are at the final phase of the process and its weight has been reduced a 60% [60] while the ones at the end of the piles are just added, and are beginning the composting process.

Therefore, every three days part of the materials located at the beginning of the pile have completed the composting period and are ready to be taken out of the pile. Considering the reduction of weight, the initial 72 T will be reduced to 30 T of final mature compost. The stable compost is sifted with a trammel screen and then can be market as soil fertilizer. The empty space that is generated after the extraction of the mature compost is used to proceed with the turning process with the aid of a wheel loader. The overall pile is bring forward not only promoting the aeration of the waste but also leaving space for the new coming waste. This operational procedure is repeated every three days.

Three operators are sufficient to perform these tasks. The operators will work every day a total of 8 hours. The task to be performed is based on:

1. Loading the mature compost to the screen (every three days).
2. Turning the remaining non-mature compost to promote aeration bringing it forward (every day).
3. Prepare the mixture of the new received materials and add them to the windrow using the available empty space (every three days).

All the activities are carried out with the aid of the wheel loader. This machine can turn 200 m^3 of waste per hour. Therefore, if the overall pile occupies a volume of approximately 4,000 m^3, 20 hours of work are needed to turn the whole pile. As the pile needs to be turned before there is a new entrance of waste (before three days) these 20 hours of work will be performed in three days (6.67 hours of turning every day).

The yield of the hypothetic screen is 25 m^3/h. Therefore, if every three days 30 T (60 m^3) are sifted, the screen will be active 2.4 hours every three days.

11. Environmental Impacts

11.1. Environmental Impacts of the Study

The course of the research has had some environmental impacts. Some of them are related with the carbon footprint, which is a measurement of the amount of carbon dioxide that an activity produces. As the study has been performed in site, it was necessary to travel from Barcelona (Spain) to Wukro (Ethiopia) by airplane. The carbon dioxide released on that flight was 1.9 T of CO_2 [61]. Moreover, transportation by car was also needed in order to arrive to Sheba Leather Industry and to other places where the study was carried out. The transports took on average 15 hours of driving and, therefore, 0.409 T of CO_2 were produced [61].

Apart from these activities, no other activities conducted during the research have had significant environmental impacts.

Consequently, the total study has contributed in a release of 2.309 T of carbon dioxide to the environment.

11.2. Environmental Impacts of the future Composting Plant Project

The project's impact is based on the difference between the modified future environment, as a result of the implementation of the project, and the future environmental situation in case no intervention was carried out. This impact has been determined in the operational stage.

The stage of operation of the plant has activities that produce an insignificant environmental impact, with the exception of the machines operation and the electricity required. Moreover, other negative impacts could be the occupation of the terrain, the presence of buildings, and the reception and storage of residues.

In order to determinate the environmental impact of the operational stage of the plant the carbon footprint method has been selected. The carbon footprint produced every year by the machinery including a wheel loader and a screen is compiled in *Table 11.1* below. The composting plant is operational 300 days in a year.

Machine	Operational h/year	Litres consumed/h	Total Litres consumed/year	kg CO_2 released/L	T of CO_2 released/year
Wheel Loader	2,001	8	16,008	2.39*	38.26
Trommer Screen	292.8	4	1,171.2	2.39*	2.80

* [62]
Table 11.1: Gasoil Consume of the Composting Plant

The carbon footprint produced every year by the electricity used in the site office, including one computer, one fan and three light bulb, is compiled in *Table 11.2* below.

Electrical Devices	Power (W)	Operational hours/day	kWh/ day	kWh/ year	kg CO_2 released/KWh	TOTAL kg CO_2 released/year
1 Fan	50	4	1.8	540	0.308	166.32
3 Light Bulb	300	4				
1 Computer	100	4				

Table 11.2: Electricity Consume of the Composting Plant

Therefore, a total of 41.23 T of CO_2 are released to the environment every year.

In the surroundings, there is not a significant contribution to the environmental imbalance. There is a generation of gases and an emission of particles but, at least, it is nothing else than a return of natural products that were taken from the nature. As an example, the carbon dioxide released is restoring the vegetation that was once used to feed the animals. As a consequence, the resulting environmental impact of the process is minimal.

On the other hand, also considering the surroundings, it will create a positive environmental impact for the farmers that harvest their crops nearly. Currently, the company is not performing any special previous treatment to the waste before disposing it. Consequently, is polluting the neighbouring areas and damaging the quality of the terrain. If a composting plant is implemented, not only part of the wastes will be managed but also the resulting compost will be used in order to recover the quality of the soil and to promote the crops of the farmers.

Yearly 3,400 tonnes of tannery wastes will be used in order to obtain a benefit, the compost. During the performance of the composting process the weight of the material decreases significantly due to the evaporation of part of it through water vapour and CO_2. Therefore, considering that the initial compost reduces its weight approximately a 60% [60], 2,880 tonnes of mature compost will be generated every year and can be apply in the surrounding terrain.

Finally, in order to avoid an adverse impact of the leachates, it is necessary to treat them before discharging them directly to the nature.

12. Economical Aspects

12.1. Economic Requirements of the Study

The study entailed some expenses originated mainly by required material for the sampling, transportation, stay costs and salaries of the people involved in the project. The total rates are compiled in *Table 12.1* below and reveal a total amount of 5,584.55 €.

CATEGORY	EXPENSES (€)
Material	
Containers	33.75 €
Gloves	5.00 €
Weight	7.50 €
Soil Thermometer	8.35 €
EM (16L)	12.50 €
Stay	
Accommodation	400.00 €
Alimentation	250.00 €
Transportation	
Flight	850.00 €
Car	20.00 €
Salaries	
Tutor of the project	300.00 €
Project Leader	3,600.00 €
Managers from Sheba	90.30 €
Staff	7.15 €
TOTAL	**5,584.55 €**

Table 12.1: Overview of the expenses generated during the performance of the study

The salaries are detailed in *Table 12.2* based on the average wage costs in Ethiopia and Spain [63].

Currency change at 11th of January 2018: 1 Euro (€) = 32.59 ETB (birr).

	Number	Hours	Salary (€/h)	TOTAL (€)
Tutor of the project	1	10	30	300.00 €
Project Leader	1	300	12	3,600.00 €
Managers from Sheba	3	7	4.3	30.10 €
		4		17.20 €
		10		43.00 €
Staff	5	20	0.13	2.60 €
		20		2.60 €
		5		0.65 €
		5		0.65 €
		5		0.65 €
TOTAL				**3,997.45 €**

Table 12.2: Detailed salaries of the professionals involved in the project

12.2. Economic Requirements of the future Composting Plant Project

In this section the total operational costs of the composting plant are determined. For that purpose, the profits and losses generated at the plant every year have been calculated. The results are shown in *Table 12.3*.

These costs include the procurement of the organic wastes, the gasoil for the machinery, electricity, the operators' salaries, and others.

Economical Balance			
PROFITS		**LOSSES**	
Tannery wastes from Sheba	3,400.00 €	3 operators salaries	18,000.00 €
Sell of compost	5,760.00 €	Depreciation rate of the machinery	4,000.00 €
		Gasoil	9,448.56 €
		Electricity	81.00 €
		Taxes and others	10%
TOTAL	**9,160.00 €**	**TOTAL**	**34,682.52 €**

Table 12.3: Overview of the profits and losses generated by the composting plant during one operational year

Consequently, a financial aid of approximately 25,500 € is required to assure the composting plant's continuity.

The calculations are explained and detailed as follows:

In order to determinate the waste fee and the price of compost, the rates in Spain have been examined. In Spain a company has to pay 10 €/T of waste generated and the price of compost is of approximately 25 €/T [64]. Considering the economical differences in case of Ethiopia, the mentioned values have been adjusted to: 1 €/T of wastes from tannery, and 2 €/T of compost.

In case of the operators, a salary of 3 €/hour has been considered [63].

A depreciation rate of 25 years has been determined for the machinery. The cost of the equipment has been approximated to 50,000 €, in case of the wheel loader, and also 50,000 € in case of the screen.

The price of the gasoil in Ethiopia is of 0.55 €/litre [65]. The price of electricity is 0.15 €/kWh.

CONCLUSIONS

This research was undertaken towards analysing the current status of the waste management practices in Sheba Leather Industry in order to propose further options that could be beneficial not only for the company but also for the environment. Consequently, it is important to keep in mind that the principal objective of this project was to evaluate the solid wastes generated with the aim of suggesting an advantageous solution, and make a study of its feasible implementation.

Taking into account the mentioned purpose and the course of the project, the following conclusions can be drawn:

- It was of great importance to have an accurate understanding of the working methodology used in Sheba. It was possible to obtain an extensive knowledge of all the different procedures carried out in the tannery due to different detailed visits that were conducted. The overall leather processing operations can be divided in four groups: beamhouse, tanning, re-tanning, and finished processes. They were defined and studied as explained in *section 4.1*.

- The next stage was based on understanding the current waste management practices of the company. Again, different visits were conducted and it was identified that, presently, no previous treatments are being performed in case of solid waste. The industry possesses an open disposal area (landfill) in which all the solid wastes are disposed directly after its generation. Moreover, the landfill is about to be full and, consequently, Sheba is at this time negotiating to purchase a new terrain. On the other hand, in case of the effluent, there is a wastewater treatment plant that improves the quality of the water. However, the treated water does not meet all the national standards and some enhancements need to be carried out. The values of the treated water's parameters are compiled in *section 3.3.3*.

- In case of the sludge, after visiting the Composting Plant of Jorba, it was suggested the possibility of making compost with crushed wood and sludge from tannery (ratio 3:1) in order to dry the sludge and reduce its weight by 70%. The composting method is based on turned windrows of great dimensions up to 80x18x3 m. The process lasts 8 weeks and the final compost needs to be screened. The sifted compost is brought to a secure landfill while 80% of the remaining crushed wood can be reused for future processes.

- The generation rate of all the solid wastes generated was determined and it can be reduced to an annual generation of 5,190 tonnes of solid wastes including hides and skins activities, and sludge. It is evident that this immense amount of waste cannot be disposed randomly and, therefore, a possible solution to deal with part of them was introduced. The detailed generation rate values individualized depending on their origin and nature are exposed in *section 10.1.2.*

- In addition to an estimation of the amount of solid wastes generated, it was found necessary a characterization of the nature of the wastes. The available material only permitted a determination of the pH and moisture values. As a consequence, a hypothesis of the other parameters was made based on the data provided by another tannery. The physicochemical characterization results are compiled in *section 10.1.3*. It can be seen that the characteristics of each of the solid wastes are linked to the conditions in which the correspondent operation stage that generate them was carried out.

- From literature and experience it has been determined the possibility of making compost from the non-containing chrome waste (hair, trimmings and fleshings). Eight samples of 9 kg were prepared with different proportions of these wastes (3 kg) and other organic waste (6 kg) such as browns, greens, cattle manure, ash, soil and old compost. From the first sampling it can be affirm that, even the temperature did not raise to the expected values, the decomposition occurred. The composting process was being carried out successfully and only the hair waste was hard to decompose. Fleshings and trimmings decompose adequately. Moisture was insufficient occasionally because of absence of water resources.

- A second sampling was carried out in Sheba and this time two piles of 1 m^3 (about 500 kg) were prepared. Hair was refused for its hard decomposition and only fleshings and trimmings were added in a ratio of 3:1, respectively, considering its generation rate. 15 litres of Effective Microorganisms and 4.88 kg of worms were included in one of the piles to determine their supposed beneficial effect. The composting process in these piles is underway at this moment and chemists from the company are controlling it. The future results will serve to select the appropriate composting operational procedure that can be implemented in the factory.

- A basic design of a composting plant has been constructed. The composting plant is supposed to receive 24 tonnes of wastes from tannery (only fleshings and trimmings) every three days. These wastes are mixed with 48 tonnes of organic wastes so that a total of 72 tonnes (144 m^3) arrived to the composting plant every three days. The facilities of the plant are based in a reception/mixing unit (75 m^2), the piles unit (2,000 m^2), a leachate collection (400 m^2) and a site office (25 m^2). The total composting compound occupies 2,500 m^2. There is a unique pile of a great volume of 4,032 m^3 with dimensions of 90.21 m of length x 18 m of width x 3 m of height. To see the detailed characteristics of the composting plant, go to *section 10.4*.

- The machinery used is based on a wheel loader and a screen. Three operators are enough to perform the required tasks and they will work a total of 8 hours every day. The operational procedure is based on loading the mature compost to the screen, turning the pile to facilitate aeration, and mixing the received waste.

- It was also studied the environmental impact of the operation stage of a composting plant. The results shows that the total amount of carbon dioxide released to the environment every year is 41.23 T.

- The economical requirements of the research amounted to 5,584.55 € and include the procurement of the required material, the transportations costs, the stay expenses, and the salaries of the people involved in the project. For a more detailed description go to *section 12.1*.

- An economical study of the profits and losses that the composting plant has every year was carried out. The profits of the plant amounts to 9,160.00 € and the losses to 34,683.52 €. Therefore a financial aid of approximately 25,500.00

€ is required to guarantee a proper management of the plant. For a more detailed description go to *section 12.2*.

As a final conclusion, there is no doubt that due to its significant amounts and specific properties, tannery waste creates a serious environmental problem. Landfilling does not solve the problem in an environmental friendly way; quite the opposite, it is a risky option that can generate potential contamination and produce financial and energetic expenses. Therefore, solutions need to be proposed in order to make a proper use of the waste and obtain benefits from them such as energy and material recovery instead of provoking a negative environmental impact. This research has proposed and analysed the composting method as a respond to the problem. Moreover, it has design the required plant in order to treat the waste. From the mentioned study it can be concluded that composting is a feasible and appropriate waste management solution for the future of the tannery in which a benefit is going to be obtained from a waste.

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