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Reducing the environmental impact of the unhairing–liming process in the leather tanning industry

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Abstract

The environmental impact of the tanning industry is generally significant with outputs of wastes, i.e. high concentrations of organics, salts and heavy metals (chromium compounds), both in solid and liquid form, as a result. In order to bring the tanning industry more in line with present environmental thinking, various methods have been devised to reduce impacts.

The underlying study proposes a modification of the method for unhairing–liming of hides where the unhairing–liming liquids are reused several times after being recharged by reduced quantities of chemicals. The study, therefore, aims at reducing both the economic and environmental costs of the unhairing–liming process.

Experiments were carried out at lab scale with a simulation apparatus designed for the purpose. Life cycle assessment was used to evaluate the net environmental benefits of the modified method. The present value approach was used to evaluate the economic feasibility of the modified method. The quality of the produced leather was assessed by experts from the tanning sector (tanners).

On the environmental level, the modified method reduced the environmental impact of the process by 24%, COD was reduced by 50% as well as sulfide which was reduced by 73% when the process water was recycled four times.

The modified method requires some investment in new equipment and is a little more labor intensive as compared with the conventional method but does permit for savings in water up to 58% and chemicals up to 28% as well as wastewater treatment cost which was reduced by 58%. The modified method allowed for four times reuse of the unhairing–liming liquor without visibly affecting the quality of the final product of leather.

It was concluded that both the economic and the environmental costs of the unhairing–liming process were reduced relative to the same of the conventional method.

Keywords: Leather tanning industry; Unhairing-liming; Environmental impact

1. Introduction

Protection of the environment is a major concern all over the world. In Palestine, the Palestinian National Authority (PNA) has concern for the protection of the environment through the Ministry of Environmental Affairs (MEnA).

Industrial pollution control is one of the PNA's concerns because the industrial sector is considered a main environmental polluter. Tanning industry is considered one of the heavy polluting industries in Palestine. Treatment of animal hides and skins comprises the preparation and processing of this raw material, using large amounts of chemicals and enormous volumes of water and generating significant pollution loads [1].

In Palestine there are 18 tanneries, 10 of them, all relatively small, are in Hebron city. These tanneries discharge into the same manhole, from where the

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wastewater goes directly into the municipal sewer system which discharges into the wadis without any type of treatment. As a result, the tanneries in Hebron are responsible for tremendous environmental impacts [2].

Tanning and its associated operations can be a source of considerable environmental impact. Air and water pollution, widespread odors, poisoning from toxic gas, and unsafe disposal of waste are among the problems that have been experienced to a greater or lesser extent in the tanning industry [3]. However, pollution from tanneries, as from any major industry, has a negative long-term impact on the growth potential of a country, irrespective of the immediate economic benefits of production [3].

Cleaner production meets the dual objective of reducing environmental degradation resulting from discharge of pollutants into the environment and of reducing production costs [4]. Low cost modifications to current tanning practices can potentially reduce the amount of sulfides and other materials discharged with the wastewater. These changes can dramatically reduce production costs [2]. The underlying research aims at investigating the feasibility of applying cleaner production principles as a tool for improving the environmental and economical quality in the leather tanning industry.

The goal of the study is to improve the environmental quality and, therefore, the economical quality of the leather tanning industry. The objective is to reduce the environmental impact and the production cost of the unhairing–liming process by recycling the process effluent.

2. Background

2.1. Animal skin structure

Skin is of fundamental importance to the animal. It is an integral part of the animal's body; it has a variety of physiological functions carried out in a cooperative and highly regulated manner. It acts as a tough, flexible and preventive membrane to the animal helping to control form, shape and size and making direct contact with the external environment. It is involved in the regulation of body temperature, storage of food materials, protection, and extraction of waste products, sensory detection and communication of changes in the environment. Animal skin consists of three main layers epidermis, dermis and hypodermis (Fig. 1).

2.1.1. Epidermis

This is the outer most layer that consists of a continuous mass of cells and is differentiated into several regions [5].

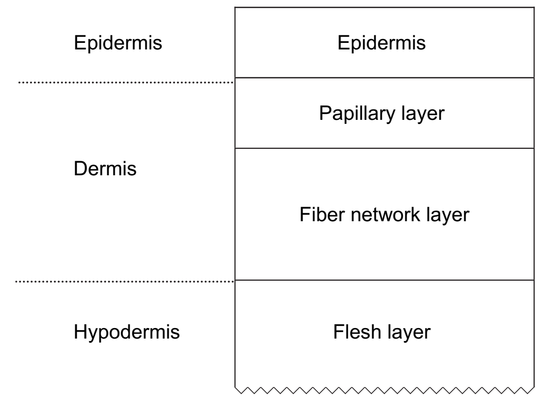

Fig. 1. Relative positions of various layers of the skin [5].

2.1.2. Dermis

The middle layer is called the dermis and has two fairly distinct regions, the papillary layer and the fiber-network layer. The papillary layer consists mainly of collagen and elastin fibers. The fiber-network layer is the main region of dermis and usually forms the major part of leather. It consists of connective tissue fibers mainly collagen fibers [5].

2.1.3. Hypodermis

The lower layer is called the hypodermis in which the skin is less dense and contains fat cells. It is often called the flesh layer and this is removed in the fleshing operation.

Only the middle layer (dermis) is used in leather making. In the operation called fleshing much of the lower layer (hypodermis) is removed, epidermal structures are loosened chemically and removed to a large extent in the process of unhairing [5].

2.2. Leather making processes

Tanning is the process of converting hides and skins into leather in three main stages:

- preparation of hides in the beam house stage;
- tanning stage;
- post-tanning or finishing stage.

2.2.1. Beam house stage

In the beam house the hides undergo processes of pretreatment.

2.2.1.1. Soaking. The purpose of soaking is to re-hydrate the hides, to remove the salt and blood and to facilitate the removal of nonstructural (non-collagenous) proteins and dirt in order to prepare the hides for further treatment [4].

2.2.1.2. Unhairing–liming. The purpose of unhairing–liming is to remove the hair and epidermis. The hides are treated with 3% sodium sulfide containing 25% sulfide and 3% hydrated lime (calcium hydroxide) in a 200% float (a solution consisting of 2 l of water per kg of skins or hides processed). The sulfide pulps the hair and the epidermis, the lime is used as a buffer to keep the pH at about 13, which causes the hides to swell, the collagen fiber network to open, and which helps the removal of the nonstructural proteins [4]. Fig. 2 presents a schematic of the unhairing–liming stage of the tanning process.

2.2.2. Tanning stage

In the tanning stage the hides are treated with an agent that displaces the intercellular water and combines with the collagen fibers increasing its resistance to heat, hydrolysis and microbial degradation. Tanning stabilizes the collagen; the tannins join with the skin protein to form leather. Chromium salts are the most widely used tannins, although vegetable and synthetic tannins are also used [6].

2.2.2.1. Chrome tanning. A tanning solution of trivalent chromium salts is used. After several hours the chromium is fixed into the hides by increasing the pH of the solution through adding an alkali such as sodium carbonate. The process takes 4–24 h [4].

2.2.2.2. Vegetable tanning. A tanning solution is prepared from bark, wood fruits, pods or roots that contain tannin. Hides are submerged in the solution for a period from one day to six weeks depending on the type of leather required [4].

2.3. Environmental impact of chemicals in the unhairing–liming process

The tanning process in general employs a significant amount of chemicals. Because usually the waste flows of the various streams are mixed, the composition of the tannery effluent is very complex. Sodium sulfide, used in the process of unhairing–liming, is one of the most dangerous materials used in the tanning process. Upon acidification, solutions containing sulfides will release hydrogen sulfide gas into the atmosphere. Hydrogen sulfide is the reduced form of sulfur. It is formed from the reduction of sulfate (SO_4^{2-}) ions under anoxic conditions according to the following equations [7]:

$$SO_4^{2-} + \text{organic matter} \rightarrow S^{2-} + H_2O + CO_2 \qquad 2.3.1$$

$$S^{2-} + H^+ \leftrightarrow HS^- \qquad 2.3.2$$

$$HS^- + H^+ \leftrightarrow H_2S \qquad 2.3.3$$

There are many problems related to the use of sulfur compounds such as the toxicity of hydrogen sulfide and its corrosiveness on the concrete such as in sewers. The presence of sulfide in wastewater may result in a poorly settling sludge besides the odor of hydrogen sulfide [8].

2.4. Cleaner production

Cleaner production is defined by UNEP as the continuous application of an integrated preventive environmental strategy applied to processes, products, and services to increase the overall efficiency and reduce risks to humans and the environment [9].

Cleaner production can improve industrial efficiency. Reducing waste generation means reducing the environmental impact of these wastes, reducing treatment costs and increasing the economic efficiency [10]. Cleaner production is applicable at various points in the activity line between thinking of the need for, and designing a product and the disposal of that product at the end of its life cycle [10]. Cleaner production involves management of resources, good housekeeping, process modification and substitution of materials or using new technologies. It promotes pollution prevention rather than end-of-pipe treatment.

2.5. Life cycle assessment

Life cycle assessment (LCA) is the process of evaluating the effects a product has on the environment over its entire life cycle. LCA can be used as decision support tool supplying information on the environmental effects of products [11].

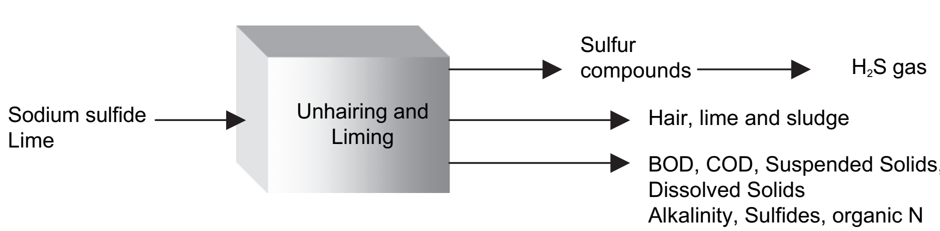

Fig. 2. Schematic of the unhairing–liming stage.

2.6. Net present value method

A cost comparison of alternatives can be done on the bases of a true financial comparison of alternatives taking into account all present and future costs. The net present value (NPV) method is one such method which relates the cost of an activity at a certain time or over a certain period to the cost at another time or over an other period given certain values for interest rate and inflation.

3. Materials and methods

3.1. Experimental approach

The conventional method of unhairing–liming of the hides uses, for each new batch of hides or skins, fresh water and chemicals according to the desired recipe and disposes the remaining liquor (Fig. 3). This study proposes a method for unhairing–liming of hides or skins that uses fresh water for the first batch of hides or skins but subsequently reuses this water for subsequent batches of hides or skins. Consequently, reduced quantities of chemicals are used.

Two different experiments were realized:

Experiment 1: the water is used two times (two cycles). Fresh water and chemicals are used to process a batch of hides in cycle 1 (conventional method). In cycle 2 the process water is recycled to process another batch of hides after decantation and adjustment of the quantities of water and chemicals (Fig. 3).

Experiment 2: the water is used five times. Fresh water and chemicals are used to process a batch of hides in cycle 1. The process water of this first cycle is reused to process a second batch of hides after decantation and adjustment of the quantities of water and chemicals (Fig. 3). The process water of the second batch is recycled for a third batch of hides. This recycling then happens two more times.

3.2. Experimental apparatus

An experimental apparatus was designed, assembled and operated to simulate a real tannery process. The apparatus consisted of three reactors of the same size. The first acted as a soaking reactor, while the second and third acted as unhairing–liming reactors.

A separate motor and timer were fixed to the soaking reactor and the unhairing–liming reactors were running on the same motor and timer so as to ensure identical operating conditions in terms of the rotational speed (Fig. 4). All the pieces of hide were processed in the same apparatus and under the same conditions. Fig. 5 illustrates an overview of the three reactors.

3.3. Materials

3.3.1. Water

Fresh tap water was used for the soaking step and the unhairing–liming step in the conventional method or cycle 1 of the modified method. The average pH was 8. In the modified method the effluent of cycle 1 was used, pH was about 12. Fresh water was also used for the adjustment of the water quantity in the modified method.

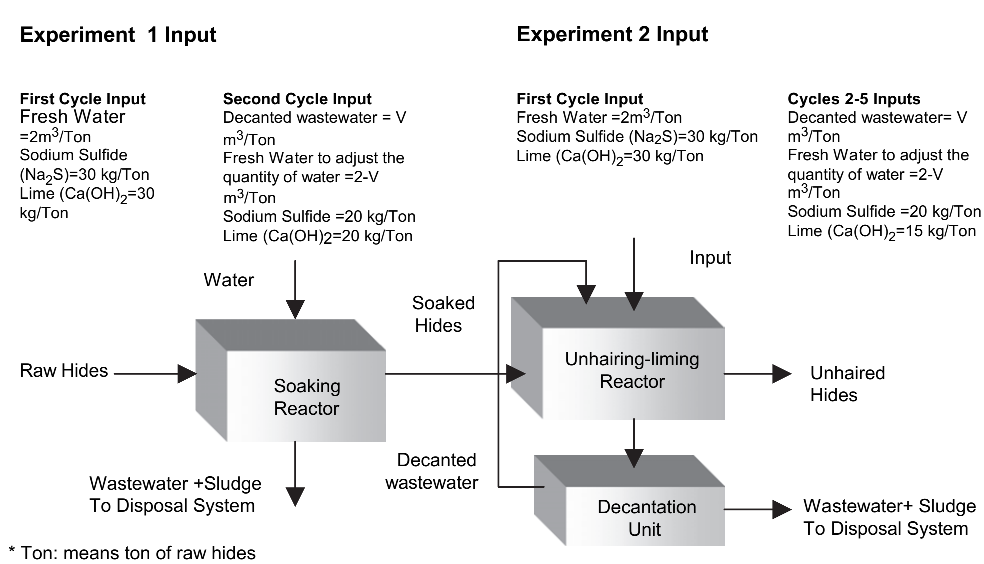

Fig. 3. Schematic diagram of the proposed unhairing–liming method where process water is used two times (experiment 1) or five times (experiment 2).

Fig. 4. Unhairing–liming reactors.

3.3.2. Chemicals

- *Sodium sulfide*: The hides were treated with sodium sulfide containing 25% sulfide. Sodium sulfide (30 kg per ton) was used in the conventional method while 20 kg per ton sodium sulfide was used in the two experiments of the new method.
- *Hydrated lime*: 30 kg per ton hydrated lime was used to treat hides in cycle 1 while 20 kg per ton was used in cycle 2.

3.3.3. Hides

Wet salted hides were used in the experiments.

3.3.4. Experimental location

The experimental work was realized at Birzeit University. The New Tanning Company in Hebron provided the hides and all chemicals needed for processing them.

3.3.5. Experimental methods

The following sequence of events took place:

Day 1: Pieces of hides were prepared of almost the same size, $30 \times 30\ cm^2$. The exact size and weight of the pieces of hide were recorded and the pieces were marked so as to differentiate between pieces processed by the conventional method and those processed in the two experiments. The pieces of hide were soaked in the soaking reactor with 200% float (quantity of water expressed as percentage of weight of hides) made in fresh tap water. The reactor was working 10 min/h for about 24 h. There were no paddles in the drums and the rotational speed was not measured.

Fig. 5. Overview of the three reactors.

Day 2: The soaked pieces were transferred to the unhairing–liming reactors. In experiment 1 two pieces were processed in each reactor or drum. One reactor was working with fresh tap water (cycle 1) and the other with the effluent of cycle 1. Subsequently, chemicals were added to the water and hides according to the recipe. In experiment 2 the soaked pieces of hides were processed in the unhairing–liming reactors. In each cycle the effluent of the previous cycle was reused.

Day 3: The unhaired pieces were unloaded and new pieces were processed in the same way. Each time the reactors were unloaded, the effluent of each reactor was analyzed the same day for sulfide (S^{2-}), sulfate (SO_4^{2-}) and COD.

Measurements of the concentrations were carried out according to the standard methods for the examination of water and wastewater. The closed reflux method was used to measure the concentration of COD. Sulfide (S^{2-}) was analyzed by the iodometric method, sulfate ion (SO_4^{2-}) was analyzed by the turbidimetric method [12].

The unhaired pieces of hide were processed in the tannery to produce the final product of the pieces of hide (now called pieces of leather).

3.4. Environmental aspects

LCA was chosen to quantify the environmental impacts of the modified method proposed in this study compared to environmental impacts produced by the conventional method. The environmental impacts were evaluated using the SimaPro 5 software [13]. All data were sent to the UNESCO_IHE Institute for Water Education to be analyzed using the SimaPro 5 [14]. The analysis of the data resulted in the determination of the environmental impact of the various processes. The impacts found were expressed in eco-points.

3.5. Economical aspects

To evaluate the economical benefits of recycling the unhairing–liming effluent, the following steps were carried out:

1. Determination of the one-time costs (US$) for investment in new equipment and the training of the staff needed for operating the modified method.
2. Determination of the annual operational costs (US$ per year) from extra labor and reduced costs of water and chemicals needed for the modified method.

3. Determination of the net present value of the one-time investment and training costs and the annually returning operational costs.

NPV was calculated according to the equation [15]:

$$\mathrm{NPV}=\sum_{n=1}^{t}\left[\frac{\mathrm{CF}_n}{(1+k)^n}\right]-I_0 \tag{3.1}$$

where NPV is the net present value, CF_n the annual cash inflow, I_0 the investment in year zero, k the interest rate, and n the number of years.

3.6. Quality assessment

Pieces of leather processed in the conventional method and in experiments 1 and 2 of the modified method were sent to six tanners to evaluate their quality. The marks, used to differentiate between pieces processed by the conventional method and by the new methods, were removed and replaced by code numbers unknown to the tanners. The pieces processed in the first cycle of experiment 1 and those processed in the second cycle of experiment 1 and the second through the fifth cycle of experiment 2 were mixed.

The tanners were asked to examine the pieces of leather and classify these according to their quality ratings. The tanners did not know which piece of leather had been processed in which manner.

3.7. Statistical methods

The average and standard deviation for each experiment were calculated. The coefficient of determination (R^2) was used to establish the relation between the concentrations expressed per ton of hides and those expressed per m^2 of hides. The chi-square test was used to determine the relationship between the type of water used and the quality of the produced leather.

4. Results

4.1. Environmental impact of COD, sulfide, sulfate and wastewater production

It was found that the average COD, sulfide and sulfate loads emitted per ton of hides were reduced when the effluent of the unhairing–liming process was recycled and reduced quantities of chemicals were added. It was also found that by increasing the number of times the process water was used (cycle number) the average loads of COD, sulfide and sulfate emitted per ton of hides were decreased (Figs. 6–8).

It was found that the average water consumption per ton of hides was reduced when implementing the modified unhairing–liming method. As the water consumption was decreased the wastewater production also decreased (Fig. 9).

Life cycle assessment was used to estimate the net environmental benefits of the modified method over the conventional. Table 1 presents the environmental impact, expressed in milli-eco-point per unit of product, for the conventional method and the different cycles of the modified method. The environmental impact of the sulfide, sulfate and hydrogen sulfide was found to be zero, the substances do not contribute to any of the standard impact categories (greenhouse effect, global warming, acidification, eutrophication, carcinogenic, etc.) (PRé Consultants [14]). Although there is some suspicion on the carcinogenicity of H_2S. This does not mean that the compounds do not have an environmental impact; it means that they have no impacts on the global level but may have an impact on the local level (PRé Consultants [14]). From Table 1 it can be concluded that the total environmental impact was reduced.

4.2. Financial aspects

The net present value method (NPV) was used to evaluate the financial feasibility of the modified method. With the cost of the modified method calculated relative to the cost of the conventional way of unhairing–liming, it can be stated that if the NPV of the modified method is positive then the method is financially accepted and if the NPV is negative then the method is financially rejected [15].

All calculations are carried out for a tannery processing 1 ton of hides per day and working 250 days per year taking into consideration the weekends, national and religious holidays. Calculations are done over a period of five years. Five years was assumed the life time of the equipment.

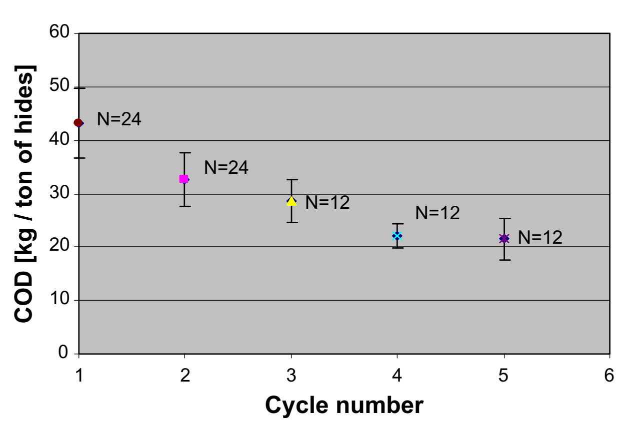

Fig. 6. Relation between COD load emitted per ton of hides and number of times the process effluent was used (cycle number). N = number of experiments multiplied by three samples of each experiment. COD values are given as mean and standard deviation of the mean values.

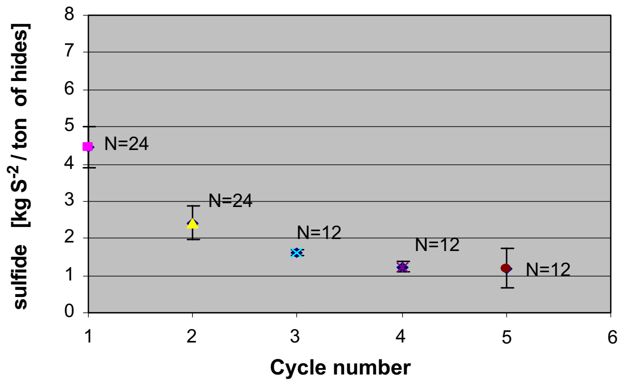

Fig. 7. Relation between sulfide loads emitted per ton of hides and number of times the process effluent was used (cycle number). N = number of experiments multiplied by three samples of each experiment. Sulfide values are given as mean and standard deviations of the mean values.

Table 2 presents the investment costs and the operational costs of the different cycles of the modified method compared to the conventional method using the present value method. It was found that financial benefits of US$29.9 per ton of hides can be achieved when the process water was recycled one time and up to US$71.3 if it was recycled four times.

4.3. Quality assessment

Pieces of raw hides were marked using small holes to differentiate between pieces processed by the conventional method and those processed by the different cycles of experiments 1 and 2 of the modified method. The unhaired hides, now called pieces of leather, were further processed in a tannery.

In experiment 1, which involves cycles 1 and 2, 24 leather pieces were examined out of which 12 were processed using the conventional method (cycle 1) and the rest were processed using the modified method (cycle 2). The main objective of examining these pieces was to assess whether there was quality difference between the pieces of hides processed in the different cycles.

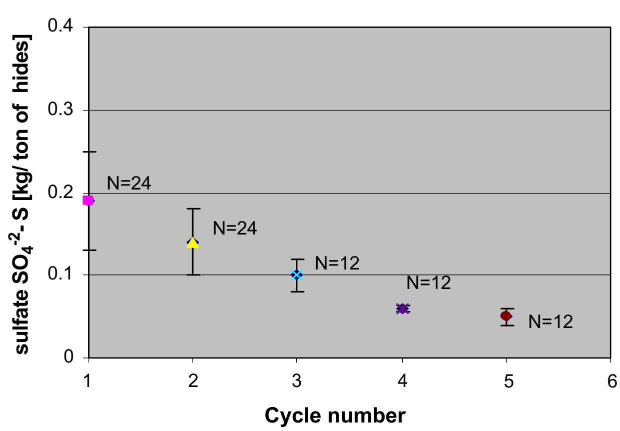

Fig. 8. Relation between sulfate loads emitted per ton of hides and number of times the process effluent was used (cycle number). N = number of experiments multiplied by three samples of each experiment. Sulfate values are given as mean and standard deviation of the mean values.

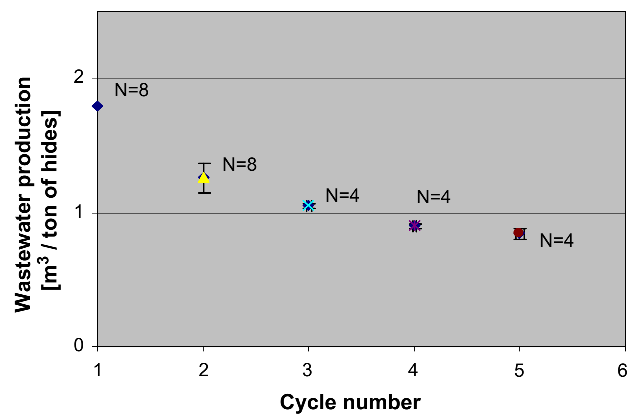

Fig. 9. Relation between wastewater production per ton of hides and number of times the process effluent was used (cycle number). N = number of experiments multiplied by three samples of each experiment. Wastewater production values are given as mean and standard deviation of the mean values.

Using the results of the quality assessment by tanners, the chi-square test was used to check if the quality of the produced leather was related to the extent of recycling of water and chemicals. It was concluded that the quality of produced leather was independent of the extent of recycling.

In experiment 2, the process water was recycled four times. Pieces of hides were marked according to the cycle number. The pieces were sent to the tannery for further tanning steps. After finishing the marks used to differentiate between pieces were removed and replaced by codes unknown to the tanners.

The pieces of leather processed in experiment 2 were mixed and examined by the tanners. Tanners were asked to classify the pieces of leather into five groups according to their quality. However, tanners opted to classify the pieces into two or three groups only. The overall number of the leather pieces was 20, four processed by the conventional method and the rest processed using the new method four in each cycle. Using the chi-square test it was found that the quality of the final product of leather was not affected by recycling the process water four times. Therefore, using the water five times in the unhairing–liming process is not affecting the quality of the final product of leather.

5. Discussion

5.1. Environmental impacts

The unhairing–liming process emits COD, sulfide and sulfate to water. COD is generated from the

Table 1
Total environmental impact of the conventional method and the different cycles of the modified method of the unhairing–liming of 1 ton of hides

	Environmental impact (mPt/unit)	Conventional method cycle 1		Modified method cycle 2		Modified method cycle 3		Modified method cycle 4		Modified method cycle 5	
		Output	Impact (mPt)[a]	Output	Impact (mPt)	Output	Impact (mPt)	Output	Impact (mPt)	Output	Impact (mPt)
COD[b]	2.88	43.2	124.2	32.64	94	28.58	82.3	22.13	63.7	21.52	62
Sulfide[b]	0.0	4.46	0.0	2.42	0.0	1.61	0.0	1.23	0.0	1.2	0.0
Sulfate[b]	0.0	0.19	0.0	0.14	0.0	0.1	0.0	0.05	0.0	0.05	0.0
Hydrogen sulfide[b]	0.0	4.95	0.0	2.72	0.0	1.81	0.0	1.36	0.0	1.32	0.0
Energy[b]	1.88	70	131.6	70.1	131.8	70.2	132	70.3	132.2	70.4	132.5
Total			255.8		225.8		214.3		195.9		194.5

[a] mPt is the unit of environmental impact in milli-eco-points.
[b] All quantities are in kg except energy in kW.

processing of the raw hides and from the chemicals used to process the hides while sulfide and sulfate are produced from the use of sodium sulfide in the process. Sulfide and sulfate may be reduced to hydrogen sulfide under anaerobic conditions.

The modified method proposed in this research used a reduced quantity of chemicals thus reducing the emissions of COD by 24% when the process water was recycled one time and up to 50% when it was recycled four times, sulfide was reduced by 46% up to 73% and sulfate was reduced by 26% up to 73%. The results compare well with those of Sendic [16] in that the pollution from COD and sulfide was reduced by 25–40% and 74–77%, respectively, when recycling of the process water was practiced. Khan et al. [6] also indicated that the procedure reduced COD and sulfide loads in the effluent. Aloy et al. [17] also stated that the direct recycling of liming float could give a decrease of 30–40% of COD.

In this study the life cycle assessment (LCA) was used to evaluate the environmental benefits of the modified method of unhairing–liming the hides. In contrast Sendic [16], Aloy et al. [17] and Khan et al. [6] did not use the life cycle assessment to evaluate the environmental benefits of recycling the unhairing–liming effluent. They evaluated the environmental benefits of recycling the process effluent by determining the reduction of the emissions of the pollutants.

Table 2
Investment costs and operational costs of the different cycles of the modified method and investment costs and operational costs of the conventional method

	Conventional method cycle 1	Modified method cycle 2	Modified method cycle 3	Modified method cycle 4	Modified method cycle 5
Investment costs ($)					
Decantation tanks	0.0	200	200	200	200
Pump	0.0	180	180	180	180
Installation	0.0	200	200	200	200
Space	0.0	1800	1800	1800	1800
Training	0.0	250	250	250	250
Total investment (I_0)	0.0	2630	2630	2630	2630
Annual operational costs (savings and extra costs) ($)					
1. Annual savings of operational cost (cash inflow)					
Water	0.0	525	725	825	875
Sodium sulfide	0.0	1875	2500	2800	3000
Lime	0.0	375	500	575	600
Wastewater treatment	0.0	710	950	1050	1160
Total annual savings ($) (total cash inflow)	0.0	3485	4675	5250	5635
2. Annual extra operational costs (cash outflow)					
Extra labor	0.0	1250	1250	1250	1250
Electricity and maintenance of new equipment	0.0	132	132	132	132
Total extra costs (total cash outflow)	0.0	1382	1382	1382	1382
Net cash inflow CF_n = total inflow − total outflow	0.0	2103	3293	3868	4253
Net present value NPV of financial benefits ($)	0.0	7488	13 213	15 979	17 832
Net present value NPV of financial benefits per ton of hides ($)	0.0	29.9	52.8	63.9	71.3

Costs are given in present value method.

The results of the study also indicated that the total environmental impact was reduced by increasing the number of times the process water was used (Fig. 10).

5.2. Economical benefits

According to UNEP [3] trials have indicated that between 20% and 50% saving of sulfide and 40–60% saving of lime could be achieved. A tannery with a throughput of 1000 hides per day could expect to save up to US$8000 per year in chemical cost. However, UNEP did not indicate the number of times the effluent is recycled.

In this study savings were achieved from a reduced consumption of water and chemicals as well as from a reduced wastewater flow. Results of the study showed that a reduction of water consumption of 36% could be achieved, if the process effluent was recycled one time and up to 58% if the process water was recycled four times.

Wastewater production decreased proportionally. Therefore, less wastewater needed to be treated lowering the consumption of energy and chemicals. Moreover, less wastewater allows for smaller wastewater treatment plants.

According to Sendic [16] a reduction of 40–70% of the total water consumption was achieved when recycling was practiced. He also stated that recycling has an indirect influence on wastewater costs, reducing the volume of the settling tank by 62% and the required area by 50%. The results of the study showed that the financial benefits of the modified method were increased by increasing the number of times the process effluent was used (Fig. 11). Therefore, the production costs of the unhairing–liming process were reduced.

In this study, the present value method was used to compare the costs per ton of hides of the conventional method with the costs per ton of hides using the modified method for different cycles. According to the findings of the underlying study, savings were achieved by implementing the modified method in spite of investments for new equipment needed for the implementation. From Figs. 10 and 11 it can be seen that the extent of reduction of environmental impact and increase of financial benefits between cycles 4 and 5 is much smaller than that between the previous cycles. In fact, the reduction and increase are approaching zero as the cycle number increases. So, it is concluded that using the process water more than four times is not of significant environmental or economic benefit.

5.3. Quality assessment

Although there are a wide variety of tests possible for assessing quality of the produced leather, these tests are usually done in special labs and are not available for the tanning industry in Palestine.

Tanners in Palestine usually use their expertise to evaluate their product. The method used in this study to evaluate the quality of the produced leather was based on the tanner's expertise.

The procedure used to evaluate the quality of the produced leather was subjective and based on the tanners' own feelings and opinions. Although the tanners are the experts, but the procedure suffers from lack of scientific indicators. The procedure was not the best but it was the only one available. Aloy et al. [17] stated that the quality of the leather produced might be affected negatively through direct recycling of unhairing–liming process water. Aloy et al. [17] also indicated that the quality of the product could be improved during the subsequent phases of leather processing. The results of the underlying study showed that the unhairing–liming liquor could be recycled four times without visibly affecting the quality of the produced leather. The results

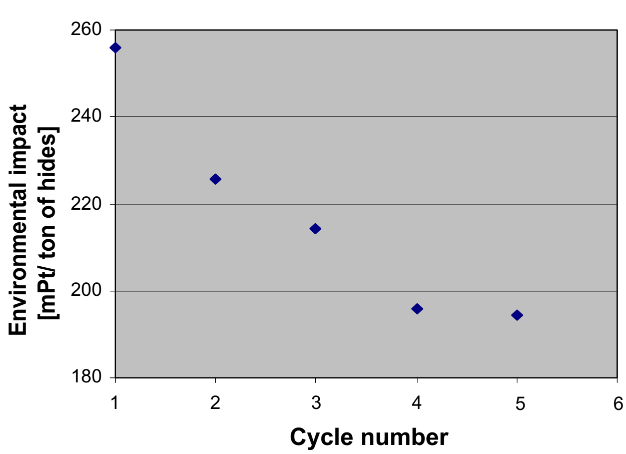

Fig. 10. Environmental impact (in milli-eco-points per ton of hides) of the conventional and of the modified method of unhairing–liming. The cycle number indicates the number of times the effluent of the process was used.

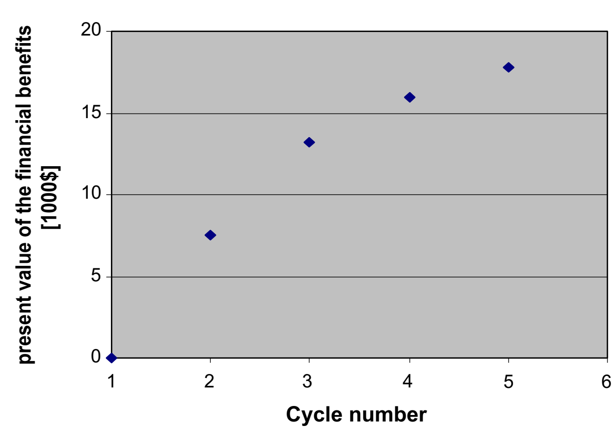

Fig. 11. Net present value of the financial benefits of the conventional method and of the method implying different cycles of the modified method.

of the study compare well with those of Cranston et al. [18] who found that when the lime liquor in the SiroLIME™ hair saving process was recycled more than 10 times, there was incomplete removal of epidermis. Cranston et al. [18] also indicated that the system has a recycle limit of 8–10 cycles.

6. Conclusions

The objective of the study was to reduce the environmental impact and the production cost of the unhairing–liming process by recycling the process effluent. Within the limitations of the study, the following conclusions were drawn:

1. The effluent of the unhairing–liming process could be recycled four times without visibly affecting the quality of the final product of leather.
2. Recycling the effluent from the unhairing–liming process reduced the environmental impact of the process per unit ton of hides by 12% when the process water was recycled one time and up to 24% when it was recycled four times.
3. Implementing the modified method of recycling the unhairing–liming process water reduced the production cost on the basis of a five-year depreciation of investment costs by US$29.9 per ton of hides if the process water was recycled one time and up to US$71.3 per ton of hides if it was recycled four times.

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