A Life-Cycle Cost Analysis of a Chromium Recycling Process System

by

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(Abstract)

Based on a global environmental concern, a need for all the tanneries in Thailand to acquire a chromium recycling process system to operate with each tannery is identified. Presently, the chromium recycling process system is available for all the tanneries. However, due to the high costs, few tanneries in Thailand have acquired the system.

The ultimate objective of this project is to reduce the cost of the system to the level that it will be attractive to all the tanneries. The objective of the life-cycle cost analysis is to identify the system's high-cost contributors for the purpose of initiating a continuous process improvement function. Once the system's high-cost contributors are identified, each of them is analyzed to see if cost reduction can be achieved. The system is modified in response to the analysis results. The modified system design will be evaluated through a life-cycle cost analysis to see how the modification has cut down on the system's total cost.

The purpose of this project is to initiate a continuous improvement process for the chromium recycling system. The initiation is accomplished with hopes of triggering future system improvement , and thus drive down the cost to an attractive level for all tanneries in Thailand. In this project, a life-cycle cost analysis of the system is accomplished, and the high-cost contributors are found. New design of the system that eliminates or reduces these high-cost contributors is considered. A life-cycle cost analysis of the new design is accomplished to compare the results. A significant reduction in system total cost will show that there is a potential for improvement, and the life-cycle cost analysis approach to reduce the total cost is the route to follow in future efforts to improve the system.

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1.0 Definition of Need

Global environmental concerns identify the need for the recycling process of the chromium element in the wastewater from tanneries all over the world. For the purpose of this study, I only focused on the tanning industry in Thailand. The motivations for the recycling process are to save money up to 21.06 million baht (Thai currency) per year on buying chromium for the tanning process, to use the chromium to the best of our capability, and to save our environment from pollution caused by excess chromium. The main purpose is to recover as much as 25% of the amount of chromium used each time from the tanning process so it can be reused the next time.

Chromium is one of the main pollutants in the wastewater from the tannery. Annually, tanneries in Thailand have discharged approximately 2.55 million cubic meters of wastewater to the environment. In the wastewater, about 197.4 tons of chromium have been discharged to the environment, and this amount is worth the equivalent of 27.75 million baht in 1992 value. By recycling the chromium in the wastewater, tannery industry can save up to 21.06 million baht each year.

Furthermore, by recycling the chromium, the amount of it from tanneries contributing to the polluted environment will decrease as much as 76%. Also, the tannery's costs for treatment of the wastewater before discharging it to the environment and the dismantling cost (cost of discharging pollutant) of chromium will decrease from 19.74 million baht.

1.1 Project Objective

In response to the above statement of need, a chromium recycling process system has been developed for use in Thailand. However, because of a lack in environmental awareness by the tanneries and the high cost of an existing system, this chromium recycling process system has not been used widely by many of the tanneries in Thailand. One way to get these tanneries to use the system and thus help cut down on pollution is to make them aware of their responsibility to the environment. Another way is to develop a system with a lower cost so they will be inclined to use it since it also can result in purchasing less chromium. As part of this project, a life-cycle cost analysis is accomplished to identify high-cost contributors for the purposes of initiating a continuous process improvement effort. By identifying high-cost contributors, determining cause-and-effect relationships, and initiating changes for improvement on a continuing basis, it is anticipated that the overall costs of the system will be reduced in the long term. The objective of this project is to discuss and demonstrate this process as it may be applied to Thailand's tanneries in the future.

2.0 Operational Requirements

2.1 Mission Definition

The function of this system being addressed is to recover and recycle the chromium element in the wastewater from the tanneries in Thailand, as much as possible and in an effective manner (i.e., use less time and convert the chromium recovered to a ready-to-use form). Also, the system is to accomplish the above at minimum total cost. It is assumed that the chromium recycling process unit will be operating approximately eight hours per day and 300 days per year. The tannery and its major components are identified in the figure 1. This figure also shows how the flow of its product, preserved raw hide, will be used in the tannery.

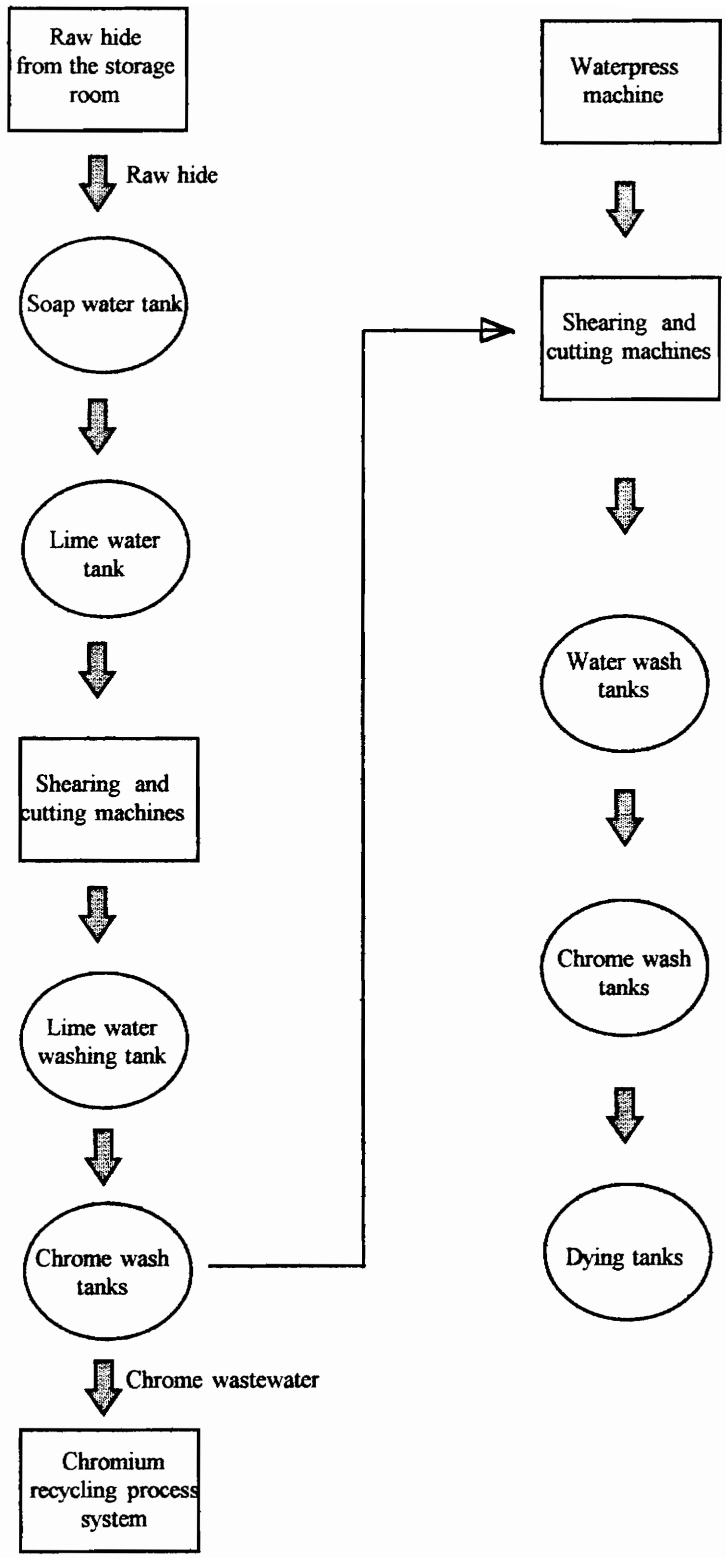

Figure 1 - Tannery Product Flow

2.2 Operational Life-Cycle

The anticipated time that the system will be in an operational use is 15 years. During this time the only operator of the system will be the tannery's employee.

2.3 Effectiveness Factors

The operating tannery for this particular chromium recycling process system will process the raw hide at the rate of 10.76 tons per day. It operates at eight hours per day and 300 days per year. Therefore, the system and the tannery should operate at the same rate. The system is expected to operate 2,400 hours per year. A mean time between failure (MTBF) of the total system is 3,600 hours, or one and a half years of operation. This number is estimated based on the motors of the mixers and pumps that are the major components in the system. Other components, such as pipes and electrical wires, have a longer MTBF than motors, and they can be repaired much faster. The mean corrective maintenance time ($\overline{M}_{ct}$) of the system is to be less than 24 hours. Most of the corrective maintenance actions, including the replacement of the corrosive pipes, should take less than two hours, assuming that new pipes are in stock. In the case of replacing motors, it should not take any longer than four hours, given that spare motors are in stock. Only when the spare components are not in stock will the maintenance actions take longer to complete. However, in any case, the maintenance action should take less than 24 hours because the supplier of these components is located in Bangkok. The travel time to Bangkok from the tannery and back should be about four hours at most.

2.4 Environment

The hot and humid climate of Thailand, plus the tannery's surrounding environment, requires the system to be able to operate effectively in temperature of 30-40^{0}C and a humidity of greater than 90% to 100%.

2.5 Program Plan and Milestones

The new chromium recycling process system's program plan and milestones are reflected in figure 2. The milestones indicate that the new chromium recycling process will be designed and constructed, and installed within the first year of life cycle. The system is designed to have a 15-year operational life. At the end of 15 years, the tannery will be re-evaluated in terms of performance requirements, and a new, more effective design of the system that recycles the chromium at a lesser cost will replace the current configuration if such a system can be developed.

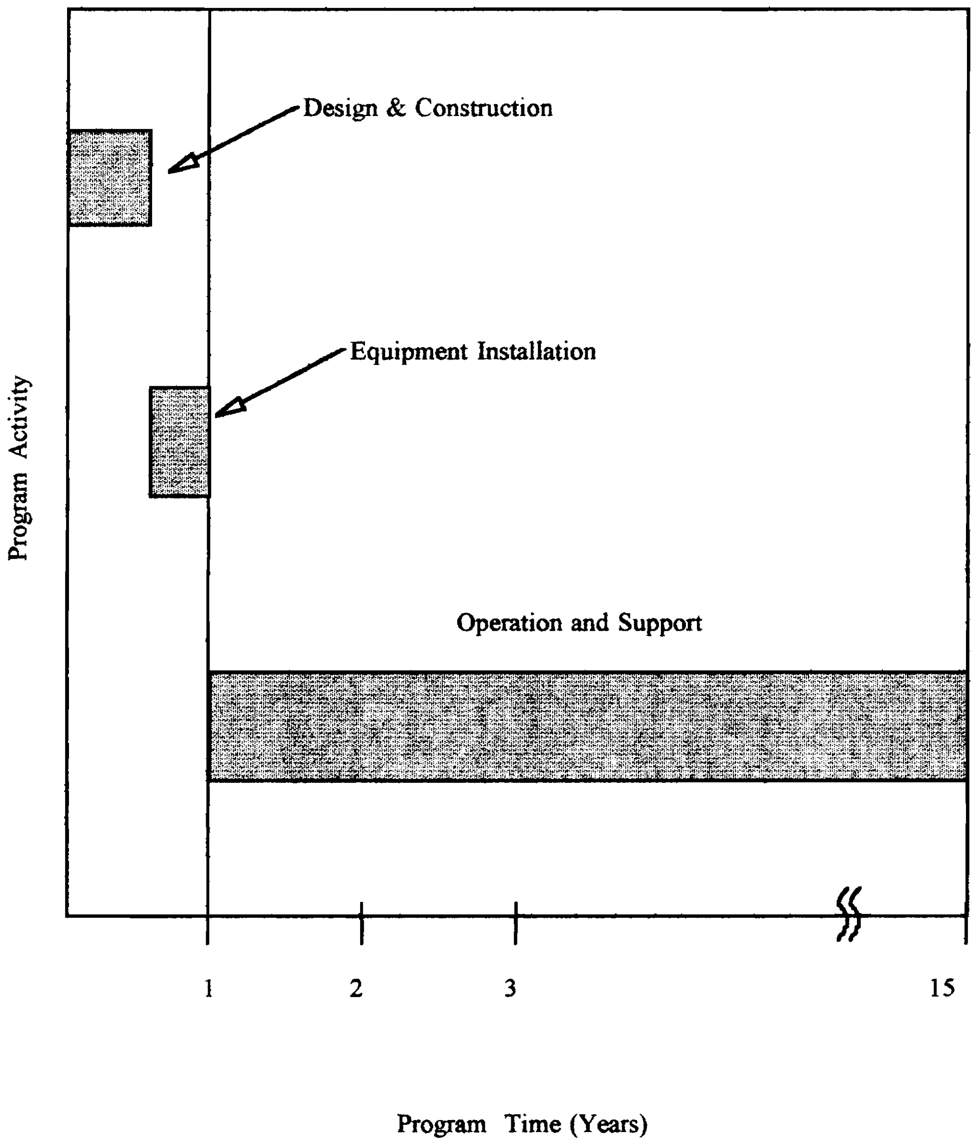

Figure 2 - Project Planning and Milestones

2.6 Operational Functional Flow

The operational functional flow for the tannery being evaluated is presented in figure 3 and figure 4. These figures describe the physical system, in figure 1, in functional terms. The tanning procedure is divided into three parts: prewash, washing, and rewash & dying. In each part, many different functions are performed. Some functions are performed using equipment that is specialized for that function. Examples of these functions are chrome wash, soak with lime water, shearing, and waterpress. Some functions are done using the equipment that can be used for many different functions. Examples of these functions are soak with water, pH stabilization, wash with water, chrome rewash & oil addition, and dying of the rewash & dying part. These functions are all done in the dying tanks. The chrome wash function is a special function addressed through this project. This function, which is represented by Block 2.1 in the figure 3, does its job and sends the product to the next function. However, it also produces wastewater that has to be treated by the chromium recycling process system.

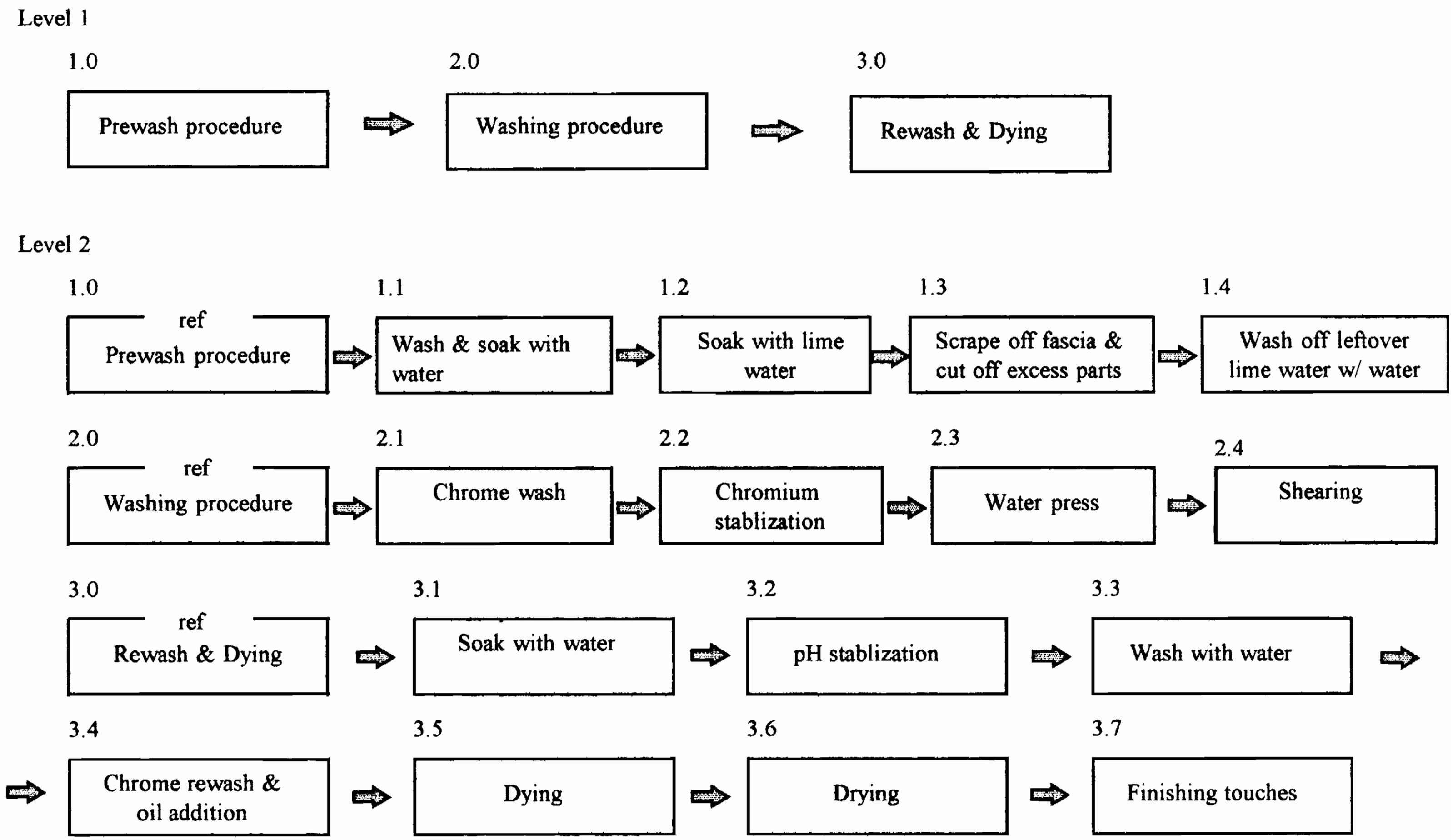

Figure 3 - Tannery Operational Functional Flow

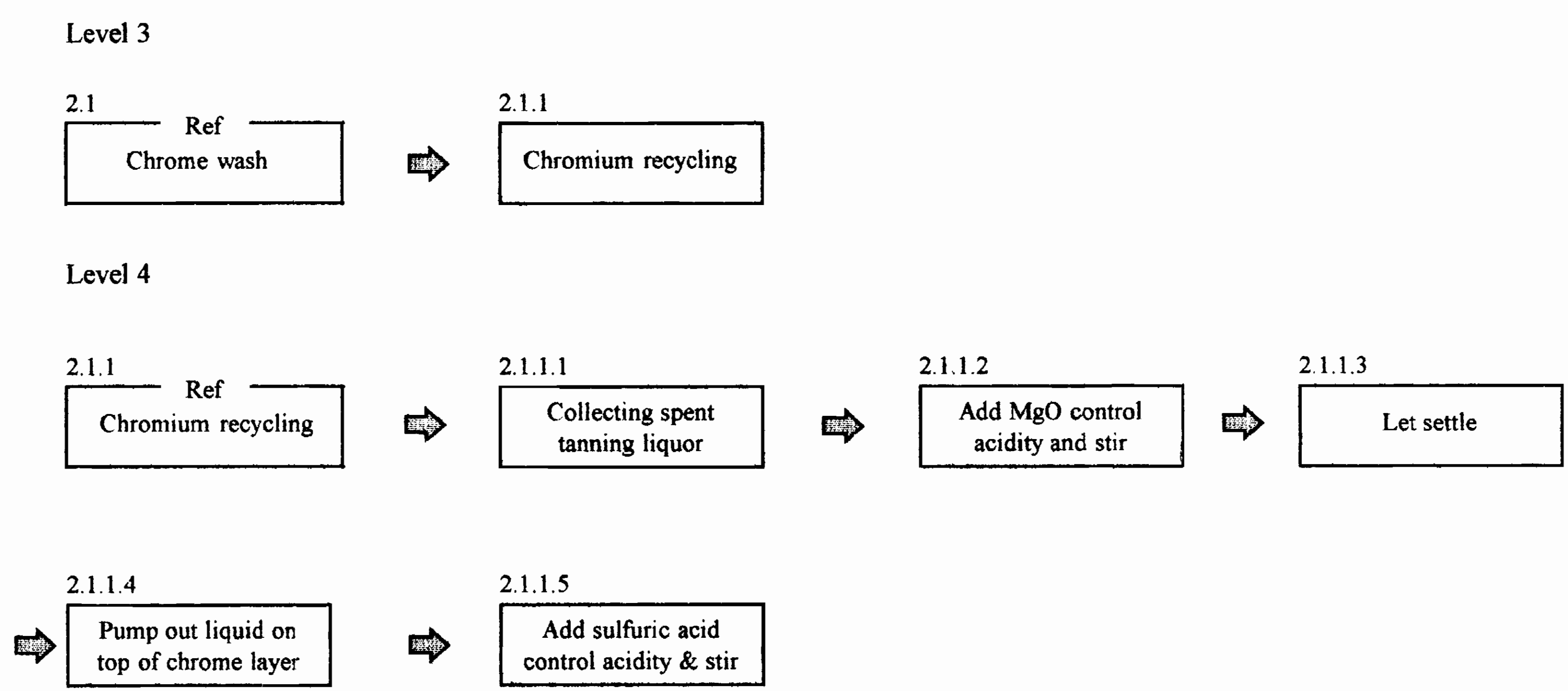

Figure 4 - Tannery Operational Functional Flow cont.

3.0 Chromium Recovery Process Design

3.1 Major Components Analysis

The major components of the system can be specified as: 1) chrome wastewater sump, 2) Chrome treatment tank, 3) MgO storage tank, 4) chrome dissolution tank, 5) sulfuric acid tank, 6) chrome liquor storage tank, 7) mixers, 8) pumps, 9) screens. These components are identified in figure 5. This figure also shows how the system's product, wastewater, flows through the components. Figure 5 is an expansion of the whole system in figure 1. It concentrates only on the Chromium Recycling Process. The Chromium Recycling Process System in figure 5 takes its input, chrome wash wastewater, from the chrome wash tanks in figure 1. Next, the system treats the wastewater; its output is the chrome liquor that can be used in chrome wash function. The output is then introduced back to the chrome wash tanks in figure 1. The operational functional flow of only the Chromium Recycling System is shown in figure 6.

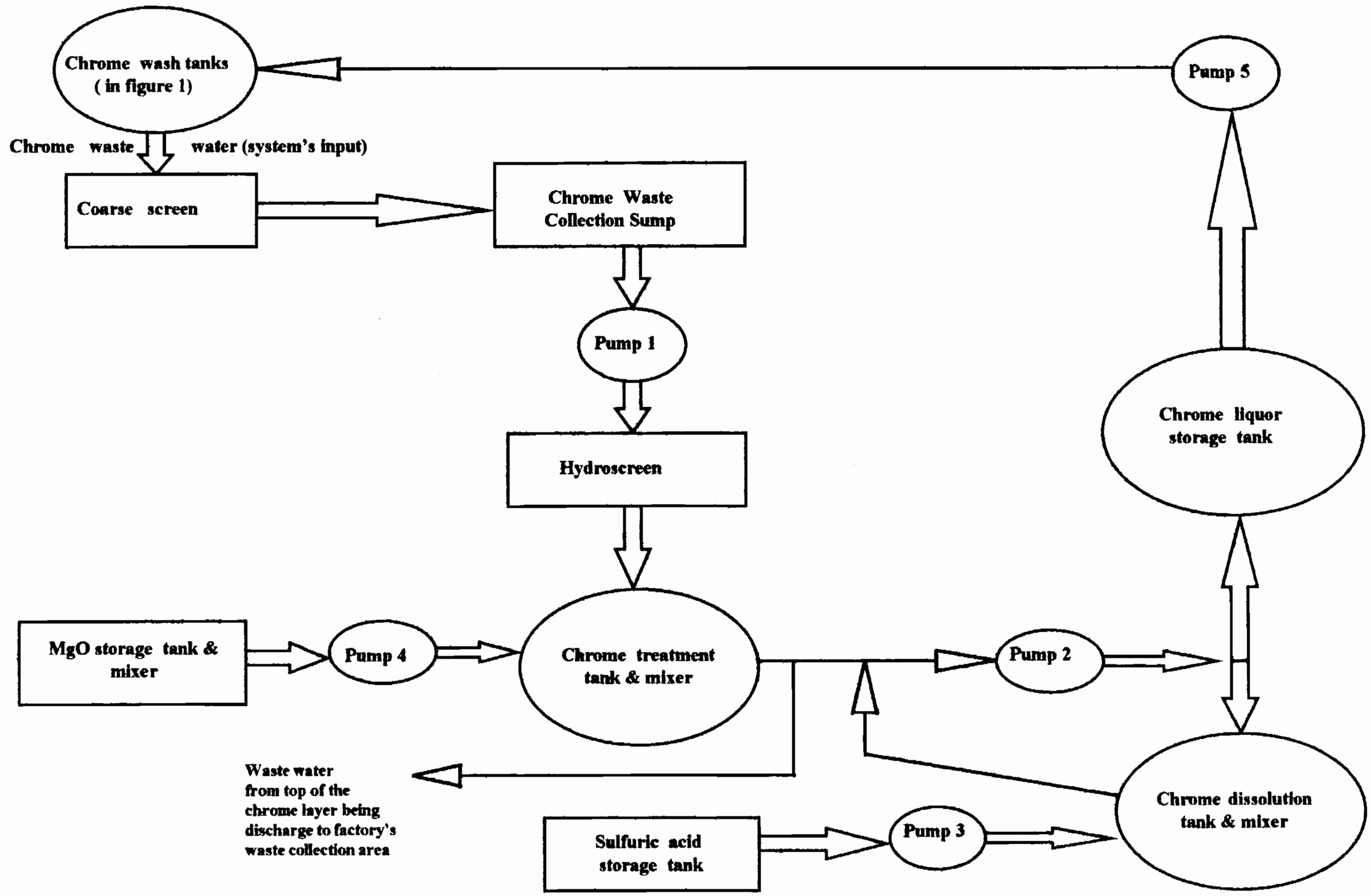

Figure 5 - Chromium Recycling Process System Product Flow

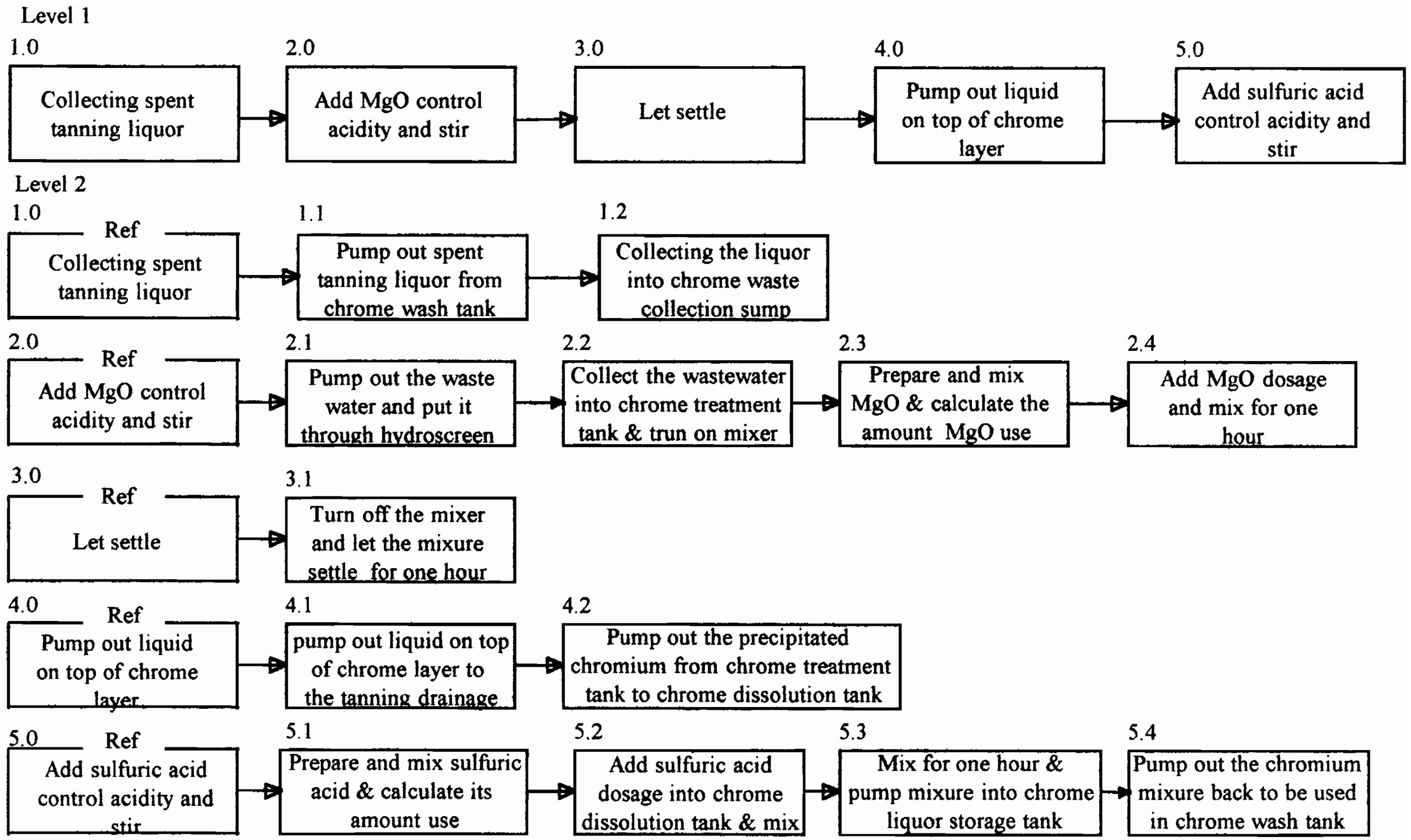

Figure 6 - Chromium Recycling System Operational Functional Flow

These components and equipment used in the installation of the system will be supplied by a single company that wins the bid for the system. The following is a description of each major component and how it plays a role for each step of the Chromium Recycling Process System function:

Step 1 : Collecting spent tanning liquor

The wastewater from the chrome wash function, the Chromium Recycling Process System's input, comes from the chrome wash tanks in figure 1 to the system. Then, it is collected in the **Chrome wastewater collection sump**, a major component of the chromium recycling process system.

Step 2 : Add MgO control acidity and stir

The wastewater in the chrome wastewater collection sump is then pumped out and flows through a **Hydroscreen**, another major component. This action separates any particles in the wastewater before they are collected in the **Chrome treatment tank**. Magnesium oxide, premixed and kept in the **Magnesium oxide tank**, is then added to the chrome treatment tank by the **chemical feed pump**. Chrome treatment tank's mixer is then turned on for one hour to mix the wastewater and magnesium oxide together.

Step 3 : Let settle

Turn off the mixer of the chrome treatment tank for one hour to let the solution settle. The **Filterpress** machine is used to help the solution settle.

Step 4 : Pump out liquid on top of chrome layer

After the magnesium oxide and the wastewater are mixed and left to settle, the liquid on top of the chrome rich layer will be pumped out and discharged to the tannery's drainage system. The chrome rich layer will then be pumped by a **screw pump** to the **chrome dissolution tank.**

Step 5 : Add sulfuric acid control acidity and stir

Sulfuric acid, premixed and stored in the **sulfuric acid storage tank,** is added to the chrome dissolution tank by another **chemical feed pump**. The mixer of the chrome dissolution tank is operated for one hour to mix the precipitated chrome and sulfuric acid dosage together. The pH of the solution is controlled to produce a quality chromium solution. The output solution is then pumped to store in the **chrome liquor storage tank** before being introduced back to the chrome wash tanks for the chrome wash function in figure 1.

3.2 Performance Specifications and Operating Condition

The chromium recycling process system will have 15-year operational life. The system requirements state that the MTBF must exceed 3600 hours. The operating environment for the system will be from 30 to 40 ^{0}C, with a humidity on the factory floor of 90% to 100%.

4.0 Maintenance Concept

The maintenance concept for the chromium recovery process system will provide guidelines for aiding the design process. The key areas covered in this section are:

a. levels of maintenance support

b. maintenance responsibilities

c. maintenance effectiveness

d. maintenance environment

Each of these topics will be addressed to describe the basic goals and constraints for the system maintenance in figure 7. This figure shows two levels of maintenance for the system, organizational-level and supplier-level.

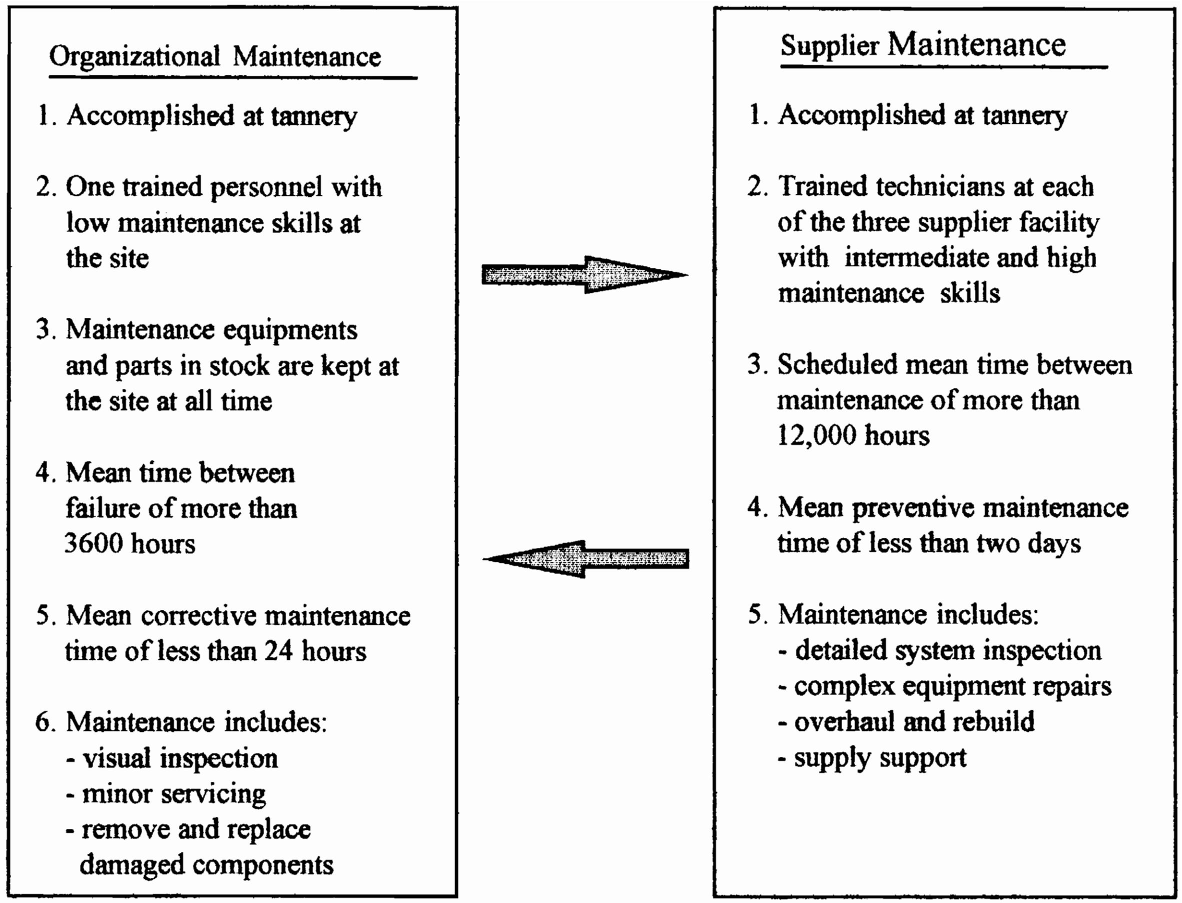

Figure 7 - System Maintenance Responsibilities Overview

The organizational maintenance is accomplished on the tannery floor by a worker with low maintenance skills. This maintenance technician is also the system's operator. The system is expected to have unscheduled mean time between maintenance ($MTBM_u$), which is the same as the MTBF, of more than 3600 hours. The corrective maintenance will take less than 24 hours to accomplish, in any circumstance. Maintenance responsibilities for this level are visual inspection, minor servicing, and the removal and replacement of damaged components. Visual inspection is done every day before and after operating hours. When damaged to the system is detected, two courses of action can be taken. If it is a minor damage, a minor servicing will be done. For example, when the hydroscreen is filled up with particles, it has to be cleaned. However, these minor services are done at the end of the working days and will not result in a system downtime. On other hand, when more serious damage is found, most likely damaged pipes or motors, a remove and replacement maintenance action is needed.

The supplier maintenance is also accomplished on the tannery floor by trained technicians with intermediate and high technical skills from the supplier sites. Scheduled maintenance is performed here. These actions are the replacements of the system's major components, such as the chrome treatment tank and the chrome dissolution tank. Thus, scheduled maintenance actions are done when the major system components are scheduled to be replaced. Therefore, a scheduled mean time between maintenance here is more than 12,000 hours, or five years of operation. The preventive maintenance will take less than two days to accomplish. Maintenance responsibilities for this level of maintenance are detailed inspection, complex equipment repairs, overhaul and rebuild, and supply support. All these maintenance responsibilities are accomplished as the maintenance actions are scheduled and if necessary.

5.0 System Life-Cycle Cost Analysis

The life cycle of the chromium recycling process system has three phases as shown in figure 2. Therefore, its life-cycle cost should make up these three phases which are a basis for the cost breakdown structure development (CBS) as seen in figure 8. However, the first two phases of its life-cycle have much less expense than the third phase. If a CBS that is made up of these phases is developed for the chromium recycling process system, the high-cost contributors of the system will be very hard to find. Therefore, all three phases of the system are combined to come up with a new CBS. Life-cycle cost of the chromium recycling process system includes all costs associated with the system in the accomplishment of its defined objective. Life-cycle cost is determined by calculating the cost of each element on year to year basis and ultimately accumulating the costs for the entire life of the system.

5.1 Development of the Cost Breakdown Structure (CBS)

The cost breakdown structure of the chromium recycling process system is tailored to fit the system's characteristic. The CBS shows where the system's costs should be allocated. The use of Activity Based Costing (ABC) will help estimate all the costs of the system more accurately. ABC is a cost estimating technique that link resources to functional activities. First, one needs to identify the functions and activities that need to be accomplished through a functional analysis and through functional flow diagram. Then, the type and quantity of resources required to complete each function and activity are identified. The cost of all the resources for each activity is recognized. Thereafter, each activity cost and function cost is estimated. These costs are allocated to the items in the CBS. The CBS helps us to identify where the major costs are located and thus find the way to improve and cut down the costs in that area. The new CBS for the chromium recycling process system is now shown in figure 9. The figure 9 breaks total cost into five function costs. Each of the function costs is made up of element costs that included "Design & Construction Cost," "Installation Cost," and "Operation & Support Cost," from figure 8, for that function in it.

The CBS is divided into five major functions: 1) collecting spent tanning liquor, 2) add MgO control acidity and stir , 3) let settle , 4) pump out liquid on top of chrome layer , 5) add sulfuric acid control acidity and stir. The CBS for the chromium recycling process is such that heavy emphasis is placed on "add MgO control acidity and stir" and "add sulfuric acid control acidity and stir," while little emphasis is placed on "let settle" and "collecting spent tanning liquor." These activities are high-cost "drivers" for the system.

The description of how element costs in each function are calculated and the justification of the description are shown in the following table 1.

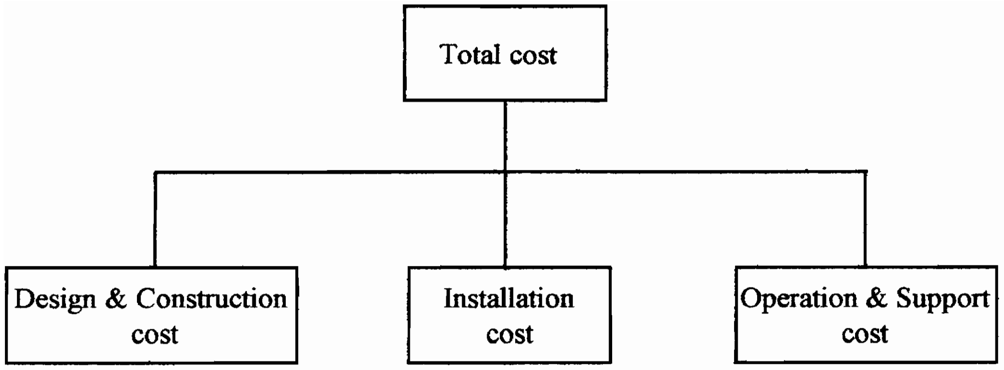

Figure 8 - A Rough Cost Breakdown Structure

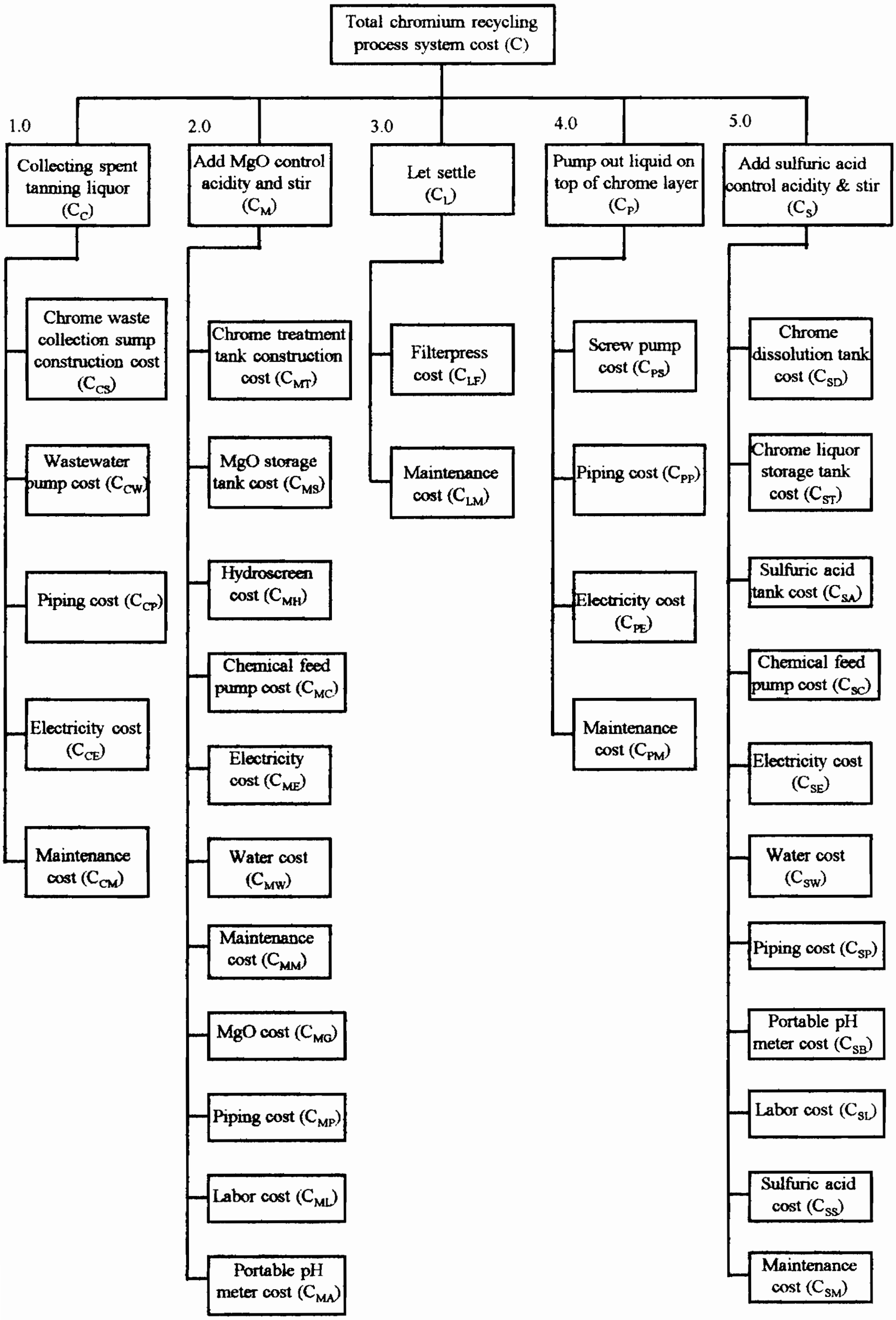

Figure 9 - System Cost Breakdown Structure

TABLE 1 DESCRIPTION OF COST CATEGORIES

Cost Category	Method of Determination (Quantitative Expression)	Cost Category Description and Justification
Total system cost (C)	$C = [C_C + C_M + C_L + C_P + C_S]$ C_C = Collecting spent liquor function cost C_M = Add MgO control acidity & stir function cost C_L = Let settle function cost C_P = Pump out liquid on top of chrome layer cost C_S = Add sulfuric acid control acidity & stir cost	Includes all future costs associated with the acquisition, operation, and maintenance of the system/equipment.
Collecting spent tanning liquor function (C_C)	$C_C = [C_{CS} + C_{CW} + C_{CP} + C_{CE} + C_{CM}]$ C_{CS} = Chrome wastewater collection sump cost C_{CW} = Wastewater pump cost C_{CP} = Piping cost C_{CE} = Electricity utilization cost C_{CM} = Maintenance cost	Includes all costs associate with the activities that make the function operate properly. Some costs are recurring cost, but chrome waste collection sump cost is nonrecurring cost.
Chrome waste collection sump cost (C_{CS})	$C_{CS} = [C_{CSA} + C_{CSB} + C_{CSC} + C_{CSD}]$ C_{CSA} = Construction labor cost C_{CSB} = Consruction material cost C_{CSC} = Cost of utilities C_{CSD} = Capital equipment cost	Includes all costs associate with acquiring and installing the chrome waste collection sump into the system.
Wastewater pump cost (C_{CW})	$C_{CW} = [C_{CWA} + C_{CWB} + C_{CWC} + C_{CWD} + C_{CWE}]$ C_{CWA} = Installation labor and equipment cost C_{CWB} = Manufacture material and labor cost C_{CWC} = Cost of utilities C_{CWD} = Capital equipment cost C_{CWE} = Transportation cost	Includes all costs associate with manufacturing , acquiring, and installing the wastewater pump into the system.
Piping cost (C_{CP})	$C_{CP} = [C_{CPA} + C_{CPB} + C_{CPC} + C_{CPD} + C_{CPE}]$ C_{CPA} = Installation labor and equipment cost C_{CPB} = Manufacture material and labor cost C_{CPC} = Cost of utilities C_{CPD} = Capital equipment cost C_{CPE} = Transportation cost	Mostly are the costs associate with installing the pipies into the system. Manufacture costs of the pipes are also considered.

TABLE 1 DESCRIPTION OF COST CATEGORIES (Continued)

Cost Category (Reference Figure 9)	Method of Determination (Quantitative Expression)	Cost Category Description and Justification
Electricity utilization cost(C_{CE})	C_{CE} = [Con x Hr x Day x Price] Con = Electricity consumption (kW) Hr = Number of hour operate Day = Number of day operate Price = Price of electricity (Baht/kW-hr)	It is the cost of electricity used by the system components in this function for the year. It is a recurring cost.
Maintenance cost (C_{CM})	$C_{CM} = [C_{CMS} + C_{CMW} + C_{CMP}]$ C_{CMS} = Chrome waste collection sump maintenance cost C_{CMW} = Wastewater pump maintenance cost C_{CMP} = Pipes maintenance cost	All costs associated with the maintenance support of the system components in this function. Specific categories cover the cost of maintaining chrome waste collection sump, maintaining wastewater pump, and maintaining all the pipes.
Chrome waste collection sump maintenance cost (C_{CMS})	$C_{CMS} = [C_{CMSA} + C_{CMSB} + C_{CMSC}]$ C_{CMSA} = Maintenance material cost C_{CMSB} = Maintenance equipment cost C_{CMSC} = Maintenance labor cost	Includes material cost, labor cost and equipment cost use to keep the chrome waste collection sump in an operating condition. The maintenance actions may be cleaning the sump, or repairing the sump.
Wastewater pump maintenance cost (C_{CMW})	$C_{CMW} = [C_{CMWA} + C_{CMWB} + C_{CMWC}]$ C_{CMWA} = Maintenance material cost C_{CMWB} = Maintenance equipment cost C_{CMWC} = Maintenance labor cost	Includes material cost, labor cost and equipment cost use to keep the wastewater pump in an operating condition. The maintenance actions may be cleaning the pump, repairing the pump, replacing its parts such as motor. Material cost here includes spare cost.
Pipes maintenance cost (C_{CMP})	$C_{CMP} = [C_{CMPA} + C_{CMPB} + C_{CMPC}]$ C_{CMPA} = Maintenance material cost C_{CMPB} = Maintenance equipment cost C_{CMPC} = Maintenance labor cost	Includes material cost, labor cost and equipment cost use to keep the the pipes in an operating condition. The maintenance actions may be replacing the corrosive pipes. Material cost here includes spare pipes cost.

TABLE 1 DESCRIPTION OF COST CATEGORIES (Continued)

Cost Category (Reference Figure 9)	Method of Determination (Quantitative Expression)	Cost Category Description and Justification
Add MgO control acidity & stir function cost (C_M)	$C_M = [C_{MT} + C_{MS} + C_{MH} + C_{MC} + C_{ME} + C_{MW} + C_{MG} + C_{MP} + C_{ML} + C_{MA} + C_{MM}]$ C_{MT} = Chrome treatment tank & mixer cost C_{MS} = MgO storage tank & mixer cost C_{MH} = Hydroscreen cost C_{MC} = Chemical feed pump cost C_{ME} = Electricity utilization cost C_{MW} = Water uses cost C_{MG} = MgO cost C_{MP} = Piping cost C_{ML} = Labor cost C_{MA} = Portable pH meter cost C_{MM} = Maintenance cost	This cost category covers all costs associated with the activities, which make the function operates. These activities are covered the manufacture, installation, operation ,and maintenance of the system components in this function. For example, the utilities cost when manufacture a component is considered here also.
Chrome treatment tank & mixer cost (C_{MT})	$C_{MT} = [C_{MTA} + C_{MTB} + C_{MTC} + C_{MTD} + C_{MTE}]$ C_{MTA} = Manufacture labor and material cost C_{MTB} = Capital equipment cost C_{MTC} = Installation labor and material cost C_{MTD} = Cost of utilities C_{MTE} = Transportation cost	These costs include costs associate with the manufacture of the tank & mixer, and installation of the tank & mixer. This cost category covers labor and material cost, capital equipment cost, and utilities cost (electricity, gas, water, etc.) used to manufacture the tank & mixer. It also covers labor, material, and transportation cost used to install the tank & mixer.
MgO storage tank and mixer cost (C_{MS})	$C_{MS} = [C_{MSA} + C_{MSB} + C_{MSC} + C_{MSD} + C_{MSE}]$ C_{MSA} = Manufacture labor and material cost C_{MSB} = Capital equipment cost C_{MSC} = Installation labor and material cost C_{MSD} = Cost of utilities C_{MSE} = Transportation cost	These costs include costs associate with the manufacture of the tank & mixer and installation of the tank & mixer same as the above.
Hydroscreen cost (C_{MH})	$C_{MH} = [C_{MHA} + C_{MHB} + C_{MHC} + C_{MHD} + C_{MHE}]$ C_{MHA} = Manufacture labor and material cost C_{MHB} = Capital equipment cost C_{MHC} = Installation labor and material cost C_{MHD} = Cost of utilities C_{MHE} = Transportation cost	These costs include costs associate with the manufacture of the hydroscreen and installation of the hydroscreen.

TABLE 1 DESCRIPTION OF COST CATEGORIES (Continued)

Cost Category (Reference Figure 9)	Method of Determination (Quantitative Expression)	Cost Category Description and Justification
Chemical feed pump cost (C_{MC})	C_{MC} = [C_{MCA} + C_{MCB} + C_{MCC} + C_{MCD} + C_{MCE}] C_{MCA} = Manufacture labor and material cost C_{MCB} = Capital equipment cost C_{MCC} = Installation labor and material cost C_{MCD} = Cost of utilities C_{MCE} = Transportation cost	These costs include costs associate with the manufacture of the pump, and installation of the pump. This cost category covers labor and material cost, capital equipment cost, and utilities cost (electricity, gas, water, etc.) used to manufacture the pump. It also covers labor, material, and transportation cost used to install the pump.
Electricity utilization cost (C_{ME})	C_{ME} = [Con x Hr x Day x Price] Con = Electricity consumption (kW) Hr = Number of hour operate (hr) Day = Number of day operate (day) Price = Price of electricity (baht/kW-hr)	This cost is the total electricity used per year by the components in this function.
Water uses cost (C_{MW})	C_{MW} = [WCon x Hide x Day x Price] WCon = Amount of water consume per ton of raw hide (m^3 / ton) Hide = Amount of raw hide in process per day (ton / day) Day = Number of day operate in a year (day) Price = Price of water (baht / m^3)	This cost is the cost of water used by the components in this function for the year.
MgO cost (C_{MG})	C_{MG} = [MgO x Hide x Day x Price] MgO = Amount of MgO used per ton of raw hide (kg / ton) Hide = Amount of raw hide in process per day (ton / day) Day = Number of day operate in a year (day) Price = Price of MgO (baht /kg)	This is the cost of MgO used in this function for the year.
Piping cost (C_{MP})	C_{MP} = [C_{MPA} + C_{MPB} + C_{MPC} + C_{MPD} + C_{MPE}] C_{MPA} = Installation labor and equipment cost C_{MPB} = Manufacture material and labor cost C_{MPC} = Cost of utilities C_{MPD} = Capital equipment cost C_{MPE} = Transportation cost	Mostly are the costs associate with installing the pipies into the system. Manufacture costs of the pipes are also considered.

TABLE 1 DESCRIPTION OF COST CATEGORIES (Continued)

Cost Category (Reference Figure 9)	Method of Determination (Quantitative Expression)	Cost Category Description and Justification
Labor cost (C_{ML})	$C_{ML} = [C_{MLA} + C_{MLB} + C_{MLC}]$ C_{MLA} = Preparing MgO cost C_{MLB} = Adding MgO cost C_{MLC} = Control acidity cost	This category covers the costs of operating personnel. A single operator operates the whole system. In this function, the labor cost is paid for the following activities: preparing MgO, adding MgO, and control acidity. The percent allocation for this function is 50%.
Portable pH meter cost (C_{MA})	$C_{MA} = [C_{MAA} + C_{MAB} + C_{MAC}]$ C_{MAA} = Manufacture material and labor cost C_{MAB} = Cost of utilities C_{MAC} = Capital equipment cost	This category covers the costs associated with manufacture the meter.
Maintenance cost (C_{MM})	$C_{MM} = [C_{MMT} + C_{MMS} + C_{MMH} + C_{MMC} + C_{MMP}$ C_{MMT} = Chrome treatment tank & mixer maintenance cost C_{MMS} = MgO storage tank & mixer maintenance cost C_{MMH} = Hydroscreen maintenance cost C_{MMC} = Chemical feed pump maintenance cost C_{MMP} = Pipes maintenance cost	All costs associated with the maintenance support of the system components in this function. Specific categories cover the cost of maintaining chrome treatment tank & mixer, maintaining MgO storage tank & mixer, maintaining all the pipes, maintaining hydroscreen, and maintaining chemical feed pump.
Chrome treatment tank & mixer maintenance cost (C_{MMT})	$C_{MMT} = [C_{MMTA} + C_{MMTB} + C_{MMTC}]$ C_{MMTA} = Maintenance material cost C_{MMTB} = Maintenance equipment cost C_{MMTC} = Maintenance labor cost	Includes material cost, labor cost and equipment cost use to keep the chrome treatment tank & mixer in an operating condition. The maintenance actions may be cleaning the tank, repairing the mixer, replacing motor of the mixer, or repairing the tank.
MgO storage tank & mixer maintenance cost (C_{MMS})	$C_{MMS} = [C_{MMSA} + C_{MMSB} + C_{MMSC}]$ C_{MMSA} = Maintenance material cost C_{MMSB} = Maintenance equipment cost C_{MMSC} = Maintenance labor cost	Includes material cost, labor cost and equipment cost use to keep the MgO storage tank & mixer in an operating condition. The maintenance actions may be cleaning the tank. repairing the tank, replacing motor of the mixer, or repairing the mixer.

TABLE 1 DESCRIPTION OF COST CATEGORIES (Continued)

Cost Category (Reference Figure 9)	Method of Determination (Quantitative Expression)	Cost Category Description and Justification
Hydroscreen maintenance cost (C_{MMH})	$C_{MMH} = [C_{MMHA} + C_{MMHB} + C_{MMHC}]$ C_{MMHA} = Maintenance material cost C_{MMHB} = Maintenance equipment cost C_{MMHC} = Maintenance labor cost	Includes material cost, labor cost and equipment cost use to keep the hydroscreen in an operating condition. The maintenance actions may be cleaning the screen, repairing the screen, replacing the screen.
Chemical feed pump maintenance cost (C_{MMC})	$C_{MMC} = [C_{MMCA} + C_{MMCB} + C_{MMCC}]$ C_{MMCA} = Maintenance material cost C_{MMCB} = Maintenance equipment cost C_{MMCC} = Maintenance labor cost	Includes material cost, labor cost and equipment cost use to keep the chemical feed pump in an operating condition. The maintenance actions may be cleaning the pump, repairing the pump, replacing its parts such as motor. Material cost here includes spare motor cost.
Pipes maintenance cost (C_{MMP})	$C_{MMP} = [C_{MMPA} + C_{MMPB} + C_{MMPC}]$ C_{MMPB} = Maintenance material cost C_{MMPC} = Maintenance equipment cost C_{MMPC} = Maintenance labor cost	Includes material cost, labor cost and equipment cost use to keep the the pipes in an operating condition. The maintenance actions may be replacing the corrosive pipes. Material cost here includes spare cost.
Let settle function cost (C_L)	$C_L = [C_{LF} + C_{LM}]$ C_{LF} = Filterpress cost C_{LM} = Maintenance cost	Includes all costs associate with the activities that make the function operate properly. Maintenance cost is a recurring cost. But filterpress cost is a nonrecurring cost.
Filterpress cost (C_{LF})	$C_{LF} = [C_{LFA} + C_{LFB} + C_{LFC} + C_{LFD} + C_{LFE}]$ C_{LFA} = Manufacture labor and material cost C_{LFB} = Capital equipment cost C_{LFC} = Installation labor and material cost C_{LFD} = Cost of utilities C_{LFE} = Transportation cost	These costs include costs associate with the manufacture of the filterpress, and installation of the filterpress. This cost category covers labor and material cost, capital equipment cost, and utilities cost (electricity, gas,water, etc.) used to manufacture the filterpress. It also covers labor, material, and transportation cost used to install the filterpress.

TABLE 1 DESCRIPTION OF COST CATEGORIES (Continued)

Cost Category (Reference Figure 9)	Method of Determination (Quantitative Expression)	Cost Category Description and Justification
Maintenance cost (C_{LM})	$C_{LM} = C_{LMF}$ C_{LMF} = Filterpress Maintenance cost	This cost includes only the maintenance cost of a filterpress.
Filterpress maintenance cost (C_{LMF})	$C_{LMF} = [C_{LMFA} + C_{LMFB} + C_{LMFC}]$ C_{LMFA} = Maintenance material cost C_{LMFB} = Maintenance equipment cost C_{LMFC} = Maintenance labor cost	Includes material cost, labor cost and equipment cost use to keep the filterpress in an operating condition. The maintenance actions may be cleaning the filterpress, repairing the filterpress. Material cost here includes spare cost.
Pump out liquid on top of chrome layer function cost (C_P)	$C_P = [C_{PS} + C_{PP} + C_{PE} + C_{PM}]$ C_{PS} = Screw pump cost C_{PP} = Piping cost C_{PE} = Electricity utilization cost C_{PM} = Maintenance cost	Includes all costs associate with the activities that make the function operate properly. Some of them are recurring cost such as electricity uses cost and maintenance cost. Others, such as screw pump cost and piping cost, are nonrecurring cost.
Screw pump cost (C_{PS})	$C_{PS} = [C_{PSA} + C_{PSB} + C_{PSC} + C_{PSD} + C_{PSE}]$ C_{PSA} = Installation labor and equipment cost C_{PSB} = Manufacture material and labor cost C_{PSC} = Cost of utilities C_{PSD} = Capital equipment cost C_{PSE} = Transportation cost	These costs include costs associate with the manufacture of the pump, and installation of the pump. This cost category covers labor and material cost, capital equipment cost, and utilities cost (electricity, gas, water, etc.) used to manufacture the pump. It also covers labor, material, and transportation cost used to install the pump.
Piping cost (C_{PP})	$C_{PP} = [C_{PPA} + C_{PPB} + C_{PPC} + C_{PPD} + C_{PPE}]$ C_{PPA} = Installation labor and equipment cost C_{PPB} = Manufacture material and labor cost C_{PPC} = Cost of utilities C_{PPD} = Capital equipment cost C_{PPE} = Transportation cost	Mostly are the costs associate with installing the pipies into the system. Manufacture costs of the pipes are also considered.

TABLE 1 DESCRIPTION OF COST CATEGORIES (Continued)

Cost Category (Reference Figure 9)	Method of Determination (Quantitative Expression)	Cost Category Description and Justification
Electricity utilization cost (C_{PE})	C_{PE} = [Con x Hr x Day x Price] Con = Electricity consumption (kW) Hr = Number of hour operate (hr) Day = Number of day operate (day) Price = Price of electricity (baht/kW-hr)	This cost is the total electricity used per year by the components in this function.
Maintenance cost (C_{PM})	$C_{PM} = [C_{PMS} + C_{PMP}]$ C_{PMS} = Screw pump maintenance cost C_{PMP} = Pipes maintenance cost	All costs associated with the maintenance support of the system components in this function. Specific categories cover the cost of maintaining screw pump, and the cost of maintaining pipes.
Screw pump maintenance cost (C_{PMS})	$C_{PMS} = [C_{PMSA} + C_{PMSB} + C_{PMSC}]$ C_{PMSA} = Maintenance material cost C_{PMSB} = Maintenance equipment cost C_{PMSC} = Maintenance labor cost	Includes material cost, labor cost and equipment cost use to keep the screw pump in an operating condition. The maintenance actions may be cleaning the pump, repairing the pump, or replacing motor of the pump.
Pipes maintenance cost (C_{PMP})	$C_{PMP} = [C_{PMPA} + C_{PMPB} + C_{PMPC}]$ C_{PMPA} = Maintenance material cost C_{PMPB} = Maintenance equipment cost C_{PMPC} = Maintenance labor cost	Includes material cost, labor cost and equipment cost use to keep the the pipes in an operating condition. The maintenance actions may be replacing the corrosive pipes. Material cost here includes spare cost.
Add sulfuric acid control acidity & stir function cost (C_S)	$C_S = [C_{SD} + C_{SA} + C_{ST} + C_{SC} + C_{SE} + C_{SW} + C_{SS} + C_{SP} + C_{SB} + C_{SL} + C_{SM}]$ C_{SD} = Chrome dissolution tank & mixer cost C_{SA} = Sulfuric acid storage tank cost C_{ST} = Chrome liquor storage tank cost C_{SC} = Chemical feed pump cost C_{SE} = Electricity utilization cost C_{SW} = Water uses cost C_{SS} = Sulfuric acid cost C_{SP} = Piping cost C_{SB} = Portable pH meter cost	This cost category covers all costs associated with the activities, which make the function operates. These activities are covered the manufacture, installation, operation ,and maintenance of the system components in this function. For example, the utilities cost when manufacture a component is considered here also.

TABLE 1 DESCRIPTION OF COST CATEGORIES (Continued)

Cost Category (Reference Figure 9)	Method of Determination (Quantitative Expression)	Cost Category Description and Justification
	C_{SL} = Labor cost C_{SM} = Maintenance cost	
Chrome dissolution tank & mixer cost (C_{SD})	$C_{SD} = [C_{SDA} + C_{SDB} + C_{SDC} + C_{SDD} + C_{SDE}]$ C_{SDA} = Manufacture labor and material cost C_{SDB} = Capital equipment cost C_{SDC} = Installation labor and material cost C_{SDD} = Cost of utilities C_{SDE} = Transportation cost	These costs include costs associate with the manufacture of the tank & mixer, and installation of the tank & mixer. This cost category covers labor and material cost, capital equipment cost, and utilities cost (electricity, gas, water, etc.) used to manufacture the tank & mixer. It also covers labor, material, and transportation cost used to install the tank & mixer.
Sulfuric acid storage tank cost (C_{SA})	$C_{SA} = [C_{SAA} + C_{SAB} + C_{SAC} + C_{SAD} + C_{SAE}]$ C_{SAA} = Manufacture labor and material cost C_{SAB} = Capital equipment cost C_{SAC} = Installation labor and material cost C_{SAD} = Cost of utilities C_{SAE} = Transportation cost	These costs include costs associate with the manufacture of the tank & mixer, and installation of the tank & mixer. This cost category covers labor and material cost, capital equipment cost, and utilities cost (electricity, gas, water, etc.) used to manufacture the tank & mixer. It also covers labor, material, and transportation cost used to install the tank & mixer.
Chrome liquor storage tank cost (C_{ST})	$C_{ST} = [C_{STA} + C_{STB} + C_{STC} + C_{STD} + C_{STE}]$ C_{STA} = Manufacture labor and material cost C_{STB} = Capital equipment cost C_{STC} = Installation labor and material cost C_{STD} = Cost of utilities C_{STE} = Transportation cost	These costs include costs associate with the manufacture of the tank & mixer, and installation of the tank & mixer. This cost category covers labor and material cost, capital equipment cost, and utilities cost (electricity, gas, water, etc.) used to manufacture the tank & mixer. It also covers labor, material, and transportation cost used to install the tank & mixer.
Chemical feed pump cost (C_{SC})	$C_{SC} = [C_{SCA} + C_{SCB} + C_{SCC} + C_{SCD} + C_{SCE}]$ C_{SCA} = Manufacture labor and material cost C_{SCB} = Capital equipment cost C_{SCC} = Installation labor and material cost C_{SCD} = Cost of utilities C_{SCE} = Transportation cost	These costs include costs associate with the manufacture of the pump , and installation of the pump. This cost category covers labor and material cost, capital equipment cost, and utilities cost (electricity, gas, water, etc.) used to manufacture the pump. It also covers labor, material, and transportation cost used to install the pump.

TABLE 1 DESCRIPTION OF COST CATEGORIES (Continued)

Cost Category (Reference Figure 9)	Method of Determination (Quantitative Expression)	Cost Category Description and Justification
Electricity utilization cost (C_{SE})	C_{SE} = [Con x Hr x Day x Price] Con = Electricity consumption (kW) Hr = Number of hour operate (hr) Day = Number of day operate (day) Price = Price of electricity (baht/kW-hr)	This cost is the total electricity used per year by the components in this function.
Water uses cost (C_{SW})	C_{SW} = [WCon x Hide x Day x Price] WCon = Amount of water consume per ton of raw hide (m^3 / ton) Hide = Amount of raw hide in process per day (ton / day) Day = Number of day operate in a year (day) Price = Price of water (baht / m^3)	This cost is the cost of water used by the components in this function for the year.
Sulfuric acid cost (C_{SS})	C_{SS} = [Sul x Hide x Day x Price] Sul = Amount of sulfuric acid used per ton of raw hide (kg / ton) Hide = Amount of raw hide in process per day (ton / day) Day = Number of day operate in a year (day) Price = Price of MgO (baht /kg)	This is the cost of sulfuric acid used in this function for the year.
Piping cost (C_{SP})	C_{SC}= [C_{SCA} + C_{SCB} + C_{SCC} + C_{SCD} + C_{SCE}] C_{SCA} = Manufacture labor and material cost C_{SCB} = Capital equipment cost C_{SCC} = Installation labor and material cost C_{SCD} = Cost of utilities C_{SCE} = Transportation cost	Mostly are the costs associate with installing the pipies into the system. Manufacture costs of the pipes are also considered.

TABLE 1 DESCRIPTION OF COST CATEGORIES (Continued)

Cost Category (Reference Figure 9)	Method of Determination (Quantitative Expression)	Cost Category Description and Justification
Portable pH meter cost (C_{SB})	$C_{SB} = [C_{SBA} + C_{SBB} + C_{SBC}]$ C_{SBA} = Manufacture material and labor cost C_{SBB} = Cost of utilities C_{SBC} = Capital equipment cost	This category covers the costs associated with manufacture the meter.
Labor cost (C_{SL})	$C_{SL} = [C_{SLA} + C_{SLB} + C_{SLC}]$ C_{SLA} = Preparing sulfuric acid cost C_{SLB} = Adding sulfuric acid cost C_{SLC} = Control acidity cost	This category covers the costs of operating personnel. A single operator operates the whole system. In this function, the labor cost is paid for the following activities: preparing sufuric acid, adding sulfuric acid, and control acidity. The percent allocation for this function is 50%.
Maintenance cost (C_{SM})	$C_{SM} = [C_{SMD} + C_{SMA} + C_{SMC} + C_{SCT} + C_{SCP}]$ C_{SMD} = Chrome dissolution tank & mixer maintenance cost C_{SMA} = Sulfuric acid storage tank maintenance cost C_{SMC} = Chemical feed pump maintenance cost C_{SMT} = Chrome liquor storage tank maintenance cost C_{SMP} = Pipes maintenance cost	All costs associated with the maintenance support of the system components in this function. Specific categories cover the cost of maintaining chrome dissolution tank & mixer, maintaining sulfuric acid storage tank, maintaining all the pipes, maintaining chrome liquor storage tank, and maintaining chemical feed pump.
Chrome dissolution tank & mixer maintenance cost (C_{SMD})	$C_{SMD} = [C_{SMDA} + C_{SMDB} + C_{SMDC}]$ C_{SMDA} = Maintenance material cost C_{SMDB} = Maintenance equipment cost C_{SMDC} = Maintenance labor cost	Includes material cost, labor cost and equipment cost use to keep the chrome dissolution tank & mixer in an operating condition. The maintenance actions may be cleaning the tank, repairing the mixer, replacing motor of the mixer, or repairing the tank.
Sulfuric acid storage tank maintenance cost (C_{SMA})	$C_{SMA} = [C_{SMA\,A} + C_{SMAB} + C_{SMAC}]$ C_{SMAA} = Maintenance material cost C_{SMAB} = Maintenance equipment cost C_{SMAC} = Maintenance labor cost	Includes material cost, labor cost and equipment cost use to keep the chrome sulfuric acid storage tank in an operating condition. The maintenance actions may be cleaning the tank, or repairing the tank.

TABLE 1 DESCRIPTION OF COST CATEGORIES (Continued)

Cost Category (Reference Figure 9)	Method of Determination (Quantitative Expression)	Cost Category Description and Justification
Chemical feed pump maintenance cost (C_{SMC})	$C_{SMC} = [C_{SMC\,A} + C_{SMCB} + C_{SMCC}]$ C_{SMCA} = Maintenance material cost C_{SMCB} = Maintenance equipment cost C_{SMCC} = Maintenance labor cost	Includes material cost, labor cost and equipment cost use to keep the chemical feed pump in an operating condition. The maintenance actions may be cleaning the pump, repairing the pump, replacing its parts such as motor. Material cost here includes spare motor cost.
Chrome liquor storage tank maintenance cost (C_{SMT})	$C_{SMT} = [C_{SMT\,A} + C_{SMTB} + C_{SMTC}]$ C_{SMTA} = Maintenance material cost C_{SMTB} = Maintenance equipment cost C_{SMTC} = Maintenance equipment cost	Includes material cost, labor cost and equipment cost use to keep the chrome liquor storage tank in an operating condition. The maintenance actions may be cleaning the tank, or repairing the tank.
Pipes maintenance cost (C_{SMP})	$C_{SMP} = [C_{SMP\,A} + C_{SMPB} + C_{SMPC}]$ C_{SMPA} = Maintenance material cost C_{SMPB} = Maintenance equipment cost C_{SMPC} = Maintenance labor cost	Includes material cost, labor cost and equipment cost use to keep the the pipes in an operating condition. The maintenance actions may be replacing the corrosive pipes. Material cost here includes spare cost.

5.2 Life-Cycle Cost of the Major System Elements

The following major system element costs are determined using the system's life expectation of 15 years. Based on an interview with Mr. Bernhard Meyhoefer, the person in charge of a chromium recovery study and an advisor in the office of industrial environment management (Thailand's ministry of industry), the average life of most major equipments in the system is seven years. These major pieces of equipment are the tanks, pumps, and screens. The other elements, such as pipes, have the average life of five years. The system in this study is a chromium recycling process system of a tannery with processing capacity of 10.76 tons of raw hide per day.

5.2.1 Collecting Spent Tanning Liquor Function Costs (C_C)

Some of the costs in this function are generated every year throughout the system's expected life; i.e., electricity cost and maintenance cost. Expected life of all the major equipment items are based on an interview with Mr. Meyhoefer. The nonrecurring cost in this function is the chrome waste collection sump cost. The costs incurred every five years and every seven years in this function are piping cost and wastewater pump cost, respectively. The total costs after 15 years for each cost category have included 4% inflation factors. A brief description of the relevant costs for the collecting spent tanning liquor function follows:

1. **Chrome Waste Collection Sump construction cost (C_{CS})** - acquisition cost for one of the major equipment items in the system. This cost is necessary, and the price for it is determined by the outside manufacturer based on the resources needed to construct the sump. The element costs that made up the cost of the sump are material cost(C_{CSB}), labor cost(C_{CSA}), equipment cost(C_{CSD}), and utilities cost (electricity, water, etc.) (C_{CSC}) that are expended in the construction of the sump. The expected life of this chrome waste collection sump is more than the expected life of the chromium recycling process system. Therefore, only a one time cost for this component of 17,250 baht is anticipated.

2. **Wastewater pump cost (C_{CW})** - an acquisition and installation cost. Its price is determined by the contractor with the best offer for all the system's components. The contractor price of the pump is calculated based on the resources used in manufacturing and installing the pump. The resource costs here are the labor and material cost(C_{CWB}), capital equipment cost (C_{CWD}), and utilities cost(C_{CWC}) used in manufacturing the pump. Also, the labor and equipment cost(C_{CWA}), and the transportation cost(C_{CWE}) used in installing the pump are considered here. The expected life of the pump is seven years. Therefore, it has to be replaced with a new pump on the eighth year. With the current acquisition cost of 68,000 baht and then again on year eight, the total cost is 168,470 baht which includes a 4% inflation factor.

3. **Piping cost (C_{CP})** - is the cost for materials & labor(C_{CPB}), capital equipment (C_{CPD}), and utilities(C_{CPC}) used in manufacturing the pipes. Equipment and labor cost(C_{CPA}) used for connecting all the pipes to different equipment (tanks, pumps, and etc.) and the transportation cost(C_{CPE}) of the pipes are considered here. The total piping cost for the whole system is 108,750 baht. However, the piping cost for this function is only 28% of the total cost, or 15,536 baht, because only pipes connecting the chrome waste collection sump to wastewater pump and to hydroscreen are needed. The average expected life of the pipes is five years. Therefore, over the system life of 15 years, on the average the pipes have to be replaced in the sixth and eleventh years.

4. **Electricity utilization cost (C_{CE})** - is an operating cost of the system and is also a yearly cost. Only the electricity used by the components in this function is considered. This cost is calculated as follows:

Wastewater pump uses 3.73 kW(Con) x 2 hr(Hr) = 7.46 kW-hr

Electricity / ton of raw hide = 7.46/10.76 = 0.6933 kW-hr/ton of raw hide

Electricity cost per year = 0.6399 x 10.76 ton of raw hide x 300 work days(Day) x 2.40 baht / kW-hr (Price)

= 5,371 baht per year

5. **Maintenance cost (C_{CM})** - is also a yearly cost. It is a cost to keep the components and the system running. For this function, maintenance cost is due to chrome waste collection sump(C_{CMS}), wastewater pump(C_{CMW}), and pipes(C_{CMP}). According to the study of the feasibility of chromium recovery from tanning wastewater in Thailand, on average, the maintenance cost for equipment is as follows:

Chrome waste collection sump	- 3% of its acquisition cost
Wastewater pump	- 10% of its acquisition cost
Pipes	- 3% of its acquisition cost

These figures are based on unscheduled maintenance actions. For example, wastewater pump may need a new motor when the old one burns out. Likewise, some section of the pipes may be replaced when it corrodes. Each of the maintenance cost is made up of the material cost (spares) ($C_{CM(\ )A}$), equipment cost($C_{CM(\ )B}$), and labor cost($C_{CM(\ )C}$), use in maintaining each component. Labor cost considered here is in addition to the operator labor cost, even though the operator of the system and the maintenance personnel are the same person. The maintenance personnel salary is paid in addition to his/her labor cost for operating the system. This maintenance personnel salary comes out of all components maintenance cost from each function.

The costs for the function are summarized in Table 2.

TABLE 2 COLLECTING SPENT TANNING LIQUOR FUNCTION COST SUMMARY(C_C)

	Cost by Program Year (Baht)															
Program Activity	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15	Total
1. Chrome Waste Collection Sump construction cost (C_{CS})	17,250	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**17,250**
2. Wastewater Pump cost(C_{CW})	68,000	-	-	-	-	-	-	100,470	-	-	-	-	-	-	-	**168,470**
3. Piping cost(C_{CP})	15,536	-	-	-	-	20,820	-	-	-	-	26,571	-	-	-	-	**62,927**
4. Electricity uses cost(C_{CE})	5,371	5,586	5,809	6,042	6,284	6,535	6,796	7,068	7,351	7,645	7,950	8,269	8,599	8,943	9,301	**107,547**
5. Maintenance cost (C_{CM})	7,784	8,095	8,419	8,756	9,107	9,471	9,849	10,243	10,653	11,079	11,522	11,983	12,462	12,961	13,480	**155,864**
Total actual cost (C)	**113,941**	**13,681**	**14,228**	**14,798**	**15,390**	**36,826**	**16,645**	**117,781**	**18,004**	**18,724**	**46,043**	**20,252**	**21,061**	**21,904**	**22,781**	**512,059**
Total present cost ($C_{8\%}$)	**105,498**	**11,729**	**11,295**	**10,877**	**10,474**	**23,208**	**9,712**	**63,637**	**9,007**	**8,673**	**19,748**	**8,042**	**7,744**	**7,458**	**7,183**	**314,285**

5.2.2 Add MgO control acidity and stir function costs(C_M)

Add MgO control acidity and stir costs are all the equipment costs, material cost and resources costs associated with this system function. Some of the costs occurred every year during the system's life of 15 years. These costs are electricity utilization cost, water utilization cost, MgO purchases cost, labor cost, and maintenance cost. Expected life of all the major equipment items are based on an interview with Mr. Meyhoefer. Piping cost is incurred every five years, and others are incurred every seven years such as chrome treatment tank and mixer acquisition cost, MgO storage tank and mixer cost, hydroscreen cost, chemical feed pump cost, and portable pH meter cost. The element costs which make up each of the costs are shown in table1. All of these costs included inflation factors of 4% per year, except labor cost, when the total costs after 15 years are calculated.

1. **Chrome treatment tank and mixer cost (C_{MT})** - an acquisition and installation cost for a major equipment in the system. Its price is determined by the contractor with the best offer for the whole system equipment cost. This cost is allocated to manufacture labor and equipment cost(C_{MTA}), capital equipment cost(C_{MTB}), installation labor and equipment cost(C_{MTC}), and utilities(C_{MTD}), (electricity, water, and etc.) . Transportation cost(C_{MTE}), of the tank is also considered, and it has an expected life of seven years. Therefore, it has to be replaced on year eight. Its total cost after 15 years is determined by adding its price now and seven years from now, taking into consideration a 4% inflation rate.

2. **MgO storage tank and mixer cost(C_{MS})** - also an acquisition and installation cost. Its price, expected life, and total cost after 15 years are calculated in the same fashion as the chrome treatment tank above.

3. **Hydroscreen cost (C_{MH})** - an acquisition and installation cost. Its price is determined by the contractor and allocated to the same cost elements as the chrome treatment tank and mixer. Its expected life is seven years; therefore, it has to be replaced once on the eighth year.

4. **Chemical feed pump cost (C_{MC})** - also an acquisition and installation cost. Its price is determined by the contractor with the best offer for all the system's equipment. It also allocated to the same cost elements as the chrome treatment tank and mixer. The expected life of the pump is seven years. Therefore, it has to be replaced with a new pump on year eight. With the acquisition cost of 120,000 baht at present time and then again in year eight, the total cost is 297,300 baht with 4% inflation factor.

5. **Electricity utilization cost(C_{ME})** - is an operating cost of the system and also a yearly cost. Only the electricity used by the components in this function is considered.

The following is how this cost in this function is calculated:

Chemical feed pump uses 0.18 kW(Con) x 0.5 hr(Hr) = 0.09 kW-hr

Chrome treatment tank mixer uses 0.746 kW(Con) x 1 hr(Hr) = 0.746 kW-hr

MgO storage tank mixer uses 0.746 kW(Con) x 1 hr(Hr) = 0.746 kW-hr

Electricity / ton of raw hide = 1.582/10.76 = 0.147 kW-hr/ton of raw hide

Electricity cost per year = 0.147 x 10.76 ton of raw hide x 300 work days(Day) x 2.40 baht / kW-hr (Price)

= 1,139 baht per year

6. Water uses cost(C_{MW}) - an operating and yearly cost. Most of the water consumption is used for cleaning equipment. An approximate amount uses is 0.1 cubic meter of water per ton of raw hide.

Water cost per year = 0.1 m^3/ ton of raw hide(Wcon) x 10.76 tons of raw hide(Hide) x 300 work days(Day) x 1 baht / cubic meter(Price)

= 323 baht

Water uses can be allocated to two places in this system in approximately the same amount. One of the places is in this function; therefore, the water cost here is 162 baht per year.

7. **MgO cost(C_{MG})** - also an operating and yearly cost.

The amount of MgO uses per year is:

1.61 kilograms of MgO / ton of raw hide(MgO) x 10.76

tons of raw hide(Hide) x 300 work days (Day)

= 5,197 kilogram of MgO per year

The MgO cost per year is:

5,197 kilogram of MgO x 14 baht per kilogram of MgO(Price)

= 72,759 baht per year

8. **Piping cost(C_{MP})** - is the cost for materials and labor(C_{MPB}), capital equipment (C_{MPD}), and utilities(C_{MPC}) used in manufacturing the pipes. Equipments and labor(C_{MPA}) used for connecting all the pipes to different equipment (tanks, pumps, and etc.) and the transportation cost(C_{MPE}) of the pipes are considered here. The total piping cost for the whole system is 108,750 baht. However, the piping cost for this function is 28% of the total cost or 31,071 baht because more connection on tanks and pumps are needed. The average expected life of the pipes is five years. Therefore, over the system life of 15 years, on average the pipes have to be replaced in the sixth year and eleventh year.

9. **Labor cost(C_{ML})** - an operating and yearly cost. It is a cost to pay the system operator which consists of one worker with organizational-level skills. This operator determines and measures the amount of MgO use(C_{MLB}) each time. He/she prepares MgO solution(C_{MLA}) and control acidity(C_{MLC}) of the chrome wastewater and MgO mixture. His/her salary is 42,000 baht per year. The salary includes direct pay, benefits, overhead , and bonuses. However, the labor cost for this system is allocated to two places equally. Therefore, the labor cost for this function is 21,000 baht per year. With 7% increase in his salary per year, the total labor cost for this function over 15 years is 527,730 baht.

10. **Portable pH meter cost(C_{MA})** - an acquisition cost with its price determined by the contractor. The cost can be allocated to capital equipment(C_{MAC}), labor and material(C_{MAA}) and utilities cost(C_{MAB}) used in manufacturing. Its seven year expected life span causes it to be replaced in year eight.

11. **Maintenance cost(C_{MM})** - is also a yearly cost. It is a cost to keep the equipment and the system running. For this function, maintenance cost is due to chrome treatment tank and mixer(C_{MMT}), MgO storage tank and mixer(C_{MMS}), hydroscreen(C_{MMH}), chemical feed pump(C_{MMC}), and pipes(C_{MMP}). According to the study of the feasibility of chromium recovery from tanning wastewater in Thailand, on average, the maintenance costs for these equipment are as follow:

Chrome treatment tank and mixer	-	3% of its acquisition cost
MgO storage tank and mixer	-	3% of its acquisition cost
Hydroscreen	-	5% of its acquisition cost
Chemical feed pump	-	10% of its acquisition cost
Pipes	-	3% of its acquisition cost

Each of these maintenance cost is allocated to material (spares)($C_{MM(\,)A}$), equipment($C_{MM(\,)B}$), and labor cost ($C_{MM(\,)C}$) used in maintenance actions involved.

The costs of the function are summarized in table 3 on the following page.

TABLE 3 ADD MgO CONTROL ACIDITY AND STIR FUNCTION COST SUMMARY(C_M)

Program Activity	Cost by Program Year (Baht)															
	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15	Total
1. Chrome treatment tank and mixer cost(C_{MT})	157,500	-	-	-	-	-	-	232,706	-	-	-	-	-	-	-	**390,206**
2. MgO storage tank & mixer cost(C_{MS})	37,500	-	-	-	-	-	-	55,406	-	-	-	-	-	-	-	**92,906**
3. Hydroscreen cost(C_{MH})	110,000	-	-	-	-	-	-	162,525	-	-	-	-	-	-	-	**272,525**
4. Chemical feed pump cost(C_{MC})	120,000	-	-	-	-	-	-	177,300	-	-	-	-	-	-	-	**297,300**
5. Electricity uses cost(C_{ME})	1,139	1,185	1,232	1,281	1,333	1,386	1,441	1,499	1,559	1,621	1,686	1,753	1,824	1,897	1,972	**22,807**
6. Water uses cost(C_{MW})	162	168	175	182	190	197	205	213	222	231	240	249	259	270	281	**3,244**
7. MgO cost(C_{MG})	72,759	75669	78696	81847	85121	88526	92062	95744	99578	103556	107698	112012	116487	121151	125997	**1,456,904**
8. Piping cost(C_{MP})	31071	-	-	-	-	41638	-	-	-	-	53141	-	-	-	-	**125,850**
9. Labor cost(C_{ML})	21000	22470	24045	25725	27531	29463	31521	33726	36078	38598	41307	44205	47292	50610	54159	**527,730**
10. Portable pH meter cost(C_{MA})	10000	-	-	-	-	-	-	14775	-	-	-	-	-	-	-	**24775**
11. Maintenance cost(C_{MM})	24282	25253	26263	27315	28408	29544	30724	31953	33232	34561	35942	37382	38875	40432	42049	**486,215**
Total actual cost(C)	**585,413**	**124,746**	**130,412**	**136,350**	**142,581**	**190,754**	**155,963**	**805,846**	**170,669**	**178,568**	**240,014**	**195,603**	**204,738**	**214,359**	**224,458**	**3,700,463**
Total present cost ($C_{8\%}$)	**542,034**	**106,944**	**103,521**	**100,217**	**97,041**	**120,213**	**90,999**	**435,399**	**85,386**	**82,713**	**102,942**	**77,674**	**75,282**	**72,989**	**70,772**	**2,164,125**

5.2.3 Let settle function costs(C_L)

Let settle costs include the costs of filterpress acquisition and maintenance. The filterpress life expectancy is seven years according to the study; therefore, over 15 years of system life another filterpress has to be purchased in year eight. However, the maintenance cost occurred every year for over 15 years. Both costs at the end of 15 years have included inflation factors of 4% per year.

1. **Filterpress cost(C_{LF})** - an acquisition cost with an expected life of seven years. The filterpress cost on the first year is 24,000 baht. This cost is based on the resource costs involved in manufacture the filterpress. These costs are manufacture labor and material cost(C_{LFA}), capital equipment cost(C_{LFB}), installation labor and equipment cost(C_{LFC}), utilities cost(C_{LFD}), and the transportation cost(C_{LFE}). It has to be replaced in year eight. Therefore, the total cost for this item after 15 years is 59,460 baht.
2. **Maintenance cost(C_{LM})** - a yearly cost. It is a cost to keep the equipment and the system running. For this function, maintenance cost is due to filterpress(C_{LMF}). Maintenance cost is allocated to the material(spares)(C_{LMFA}), equipment(C_{LMFB}), and labor cost (C_{LMFC}) used in the maintenance actions completed. On average, the maintenance cost for filterpress is 5% of its acquisition cost. The total cost for this function is 83,488 baht. However, when discounting this total cost to the present value using an 8% discount rate, the total cost is now 55,156 baht.

5.2.4 Pump out liquid on top of chrome layer function costs(C_P)

Pump out liquid on top of chrome layer costs are again associated with this function. The yearly incurred costs are electricity utilization cost, labor cost, and maintenance cost. All components expected-life values come from an interview with Mr. Meyhoefer. Piping cost in this function cost occurred every five years. Screw pump cost occurred every seven. All these costs included inflation factors of 4% per year.

1. **Screw pump cost(C_{PS})** - also an acquisition and installation cost. Its price is determined by the contractor with the best offer for all the system's equipment. The basis for this cost is allocated to manufacture labor and material cost(C_{PSB}), installation labor and equipment cost(C_{PSA}), capital equipment cost(C_{PSD}), utilities cost(C_{PSC}), and the transportation cost(C_{PSE}). The expected life of the pump is seven years. Therefore, it has to be replaced with a new pump in year eight. With the current acquisition cost of 80,000 baht and then again in year eight, the total cost is 198,200 baht when the 4% inflation factor is included.

2. **Piping cost(C_{PP})** - is the cost for materials & labor(C_{PPB}), capital equipment (C_{PPD}), and utilities(C_{PPC}) used in manufacturing the pipes. Equipments and labor cost(C_{PPA}) used for connecting all the pipes to different equipment (tanks, pumps, and etc.), and the transportation cost(C_{PPE}) of the pipes are considered here. The total piping cost for the whole system is 108,750 baht. However, the

piping cost for this function is only 14% of the total cost or 15,536 baht due to fewer connections needed. The average expected life of the pipes is five years. Therefore, over the system life of 15 years, on the average the pipes have to be replaced in the sixth and eleventh years.

3. **Electricity utilization cost(C_{PE})** - is an operating cost of the system and also a yearly cost. Only the electricity used by the components in this function is considered.

The following is a calculation for the cost of this function:

Screw pump uses 1.87 kW(Con) x 1 hr(Hr) = 1.87 kW-hr

Electricity / ton of raw hide = 1.87/10.76 = 0.1738 kW-hr/ton of raw hide

Electricity cost per year = 0.1738 x 10.76 ton of raw hide x 300 work days(Day) x 2.40 baht / kW-hr(Price)

= 1,346.4 baht per year

4. **Maintenance cost(C_{PM})** - is also a yearly cost. It is a cost to keep the equipment and the system running. For this function, maintenance cost is due to screw pump (C_{PMS}) and pipes(C_{PMP}). According to the study of the feasibility of chromium recovery from tanning wastewater in Thailand, on average, the maintenance costs for these equipment are as follow:

   Screw pump - 10% of its acquisition cost

   Pipes - 3% of its acquisition cost

   Each of these maintenance costs is allocated to material(spares)($C_{PM(\ )A}$), equipment ($C_{PM(\ )B}$), and labor cost($C_{PM(\ )C}$) used in maintenance actions involved.

The costs of the function are summarized in table 3 on the following page.

TABLE 4 PUMP OUT LIQUID ON TOP OF CHROME LAYER FUNCTION COST SUMMARY(C_P)

	Cost by Program Year (Baht)															
Program Activity	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15	Total
1. Screw pump cost(C_{PS})	80,000	-	-	-	-	-	-	118,200	-	-	-	-	-	-	-	**198,200**
2. Piping cost(C_{PP})	15,536	-	-	-	-	20,820	-	-	-	-	26,571	-	-	-	-	**62,927**
3. Electricity uses cost(C_{PE})	1,346	1,400	1,456	1,514	1,575	1,638	1,703	1,771	1,842	1,916	1,992	2,072	2,155	2,241	2,331	**26,952**
4. Maintenance cost(C_{PM})	8,486	8,805	9,157	9,523	9,904	10,301	10,712	11,140	11,587	12,050	12,531	13,033	13,554	14,097	14,661	**169,521**
Total actual cost (C)	**105,348**	**10,205**	**10,613**	**11,037**	**11,479**	**32,759**	**12,415**	**131,111**	**13,429**	**13,966**	**41,094**	**16,105**	**15,709**	**16,338**	**16,992**	**457,600**
Total present cost ($C_{8\%}$)	**97,542**	**8,748**	**8,424**	**8,112**	**7,813**	**20,644**	**7,244**	**70,839**	**6,718**	**6,469**	**17,625**	**5,998**	**5,776**	**5,563**	**5,357**	**282,876**

5.2.5 Add sulfuric acid control acidity and stir function costs(C_S)

Add sulfuric acid control acidity and stir costs are all the equipment costs, material costs and resources costs associated in this system function. Also, some of the costs occurred every year during the system's life of 15 years. These costs are electricity utilization cost, water use cost, sulfuric acid purchase costs, labor cost, and maintenance cost. Expected life of all the major equipment items are based on an interview with Mr. Meyhoefer. Piping cost incurred every five years, and others incurred every seventh year, such as chrome dissolution tank and mixer acquisition cost, sulfuric acid storage tank cost, chrome liquor storage tank cost, chemical feed pump cost, and portable pH meter cost. The element costs which make up each of the costs are shown in table1. All of these costs included inflation factors of 4% per year when the total costs after 15 years are calculated.

1. **Chrome dissolution tank and mixer cost(C_{SD})** - an acquisition and installation cost for a major piece of equipment in the system. Its price is determined by the selected contractor. This cost is allocated to manufacture labor and equipment cost(C_{SDA}), capital equipment cost(C_{SDB}), utilities (electricity, water, etc.)(C_{SDD}), installation labor and material cost(C_{SDC}), and the transportation cost(C_{SDE}). It has an expected life of seven years; and therefore, it has to be replaced in year eight. Its total cost after 15 years is determined by adding its price now and seven years from now, taking into consideration a 4% inflation rate.

2. **Sulfuric acid storage tank cost(C_{SA})** - also an acquisition and installation cost. Its price, expected life, and total cost after 15 years are calculated in the same fashion as the chrome dissolution tank above.

3. **Chrome liquor storage tank cost(C_{ST})** - the cost can be determined the same way as the above.

4. **Chemical feed pump cost(C_{SC})** - also an acquisition and installation cost. Its price is determined by the contractor with the best offer for all the system's equipment. This cost is allocated to manufacture labor and equipment cost (C_{SCA}), capital equipment cost(C_{SCB}), utilities(electricity, water, and etc.) (C_{SCD}), installation labor and material cost(C_{SCC}), and the transportation cost(C_{SCE}). The expected life of the pump is seven years. Therefore, it has to be replaced with a new pump in year eight. With the acquisition cost of 80,000 baht at present time and then again in year eight, the total cost is 198,200 baht with a 4% inflation factor.

5. **Electricity uses cost(C_{SE})** - is an operating cost of the system and also a yearly cost. Only the electricity used by the components in this function is considered.

   The following is how this cost in this function is calculated:

   Chemical feed pump uses 0.37 kW(Con) x 0.5 hr(Hr) = 0.185 kW-hr

Chrome dissolution tank mixer uses 0.746 kW(Con) x 1 hr(Hr) = 0.746 kW-hr

Electricity/ton of raw hide = 0.931/10.76 = 0.0865 kW-hr/ton of raw hide

Electricity cost per year = 0.0865 x 10.76 ton of raw hide x 300 work days(Day) x 2.40 baht / kW-hr (Price)

= 670 baht per year

6. **Water uses cost(C_{SW})** - here is another place to allocate water cost. Therefore, the water cost in this function is 162 baht per year.

7. **Piping cost(C_{SP})** - is the cost for materials (pipes) and labor(C_{SPA}), capital equipment(C_{SPB}), and utilities(C_{SPD}) used in manufacturing the pipes. Equipments and labor(C_{SPC}) used for connecting all the pipes to different equipment (tanks, pumps, and etc.) and the transportation cost(C_{SPE}) of the pipes are also considered here. The total piping cost for the whole system is 108,750 baht. However, the piping cost for this function is 43% of the total cost, or 46,607 baht. The average expected life of the pipes is five years. Therefore, over the system life of 15 years, on average the pipes have to be replaced in the sixth and eleventh years.

8. **Portable pH meter cost(C_{SB})** - an acquisition cost that can be determine the same way as the one in add MgO control acidity and stir function cost section.

9. **Labor cost(C_{SL})** - an operating and yearly cost. It is a cost to pay the system operator which consists of one worker with organizational-level skills. This cost is separated from the maintenance labor cost, even though the same person maintains and operates the system. This operator determines and measures the amount of sulfuric acid used each time(C_{SLB}). He/she prepares sulfuric acid solution(C_{SLA}) and control acidity of the chrome liquor and sulfuric acid solution mixture(C_{SLC}). Here is one of the place that labor cost is allocated. Therefore, labor cost here is 21,000 baht per year. With 7% increase in salary per year, the total labor cost for this function over 15 years is 527,730 baht.

10. **Sulfuric acid cost(C_{SS})** - also an operating and yearly cost. The amount of sulfuric acid uses per year is:

    1.82 kilograms of sulfuric acid/ ton of raw hide(Sul) x 10.76 tons of raw hide(Hide) x 300 work days(Day)

    = 5,875 kilogram of sulfuric acid per year

The sulfuric acid cost per year is:

5,875 kilogram of sulfuric acid x 4.45 baht per kilogram of sulfuric acid (Price)

= 26,144 baht per year

11. Maintenance cost(C_{SM}) - is also a yearly cost. It is a cost to keep the equipment and the system running. For this function, maintenance cost is due to chrome dissolution tank and mixer(C_{SMD}), Sulfuric acid storage tank(C_{SMA}), chrome liquor storage tank(C_{SMT}), chemical feed pump(C_{SMC}), and pipes(C_{SMP}). According to the study of the feasibility of chromium recovery process from tanning wastewater in Thailand, on average, the maintenance costs for these equipment are as follow:

Chrome dissolution tank and mixer	-	3% of its acquisition cost
Sulfuric acid storage tank	-	3% of its acquisition cost
Chrome liquor storage tank	-	3% of its acquisition cost
Chemical feed pump	-	10% of its acquisition cost
Pipes	-	3% of its acquisition cost

Each of these maintenance costs is allocated to material(spares)($C_{SM(\ )A}$) equipment($C_{SM(\ )B}$), and labor($C_{SM(\ )C}$) used in maintenance actions involved.

The costs of the function are summarized in table 5 on the following page.

TABLE 5 ADD SULFURIC ACID CONTROL ACIDITY AND STIR FUNCTION COST SUMMARY(C_S)

Program Activity	Cost by Program Year (Baht)															
	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15	Total
1. Chrome dissolution tank and mixer cost(C_{SD})	120,000	-	-	-	-	-	-	177,300	-	-	-	-	-	-	-	**297,300**
2. Sulfuric acid storage tank(C_{SA})	4,500	-	-	-	-	-	-	6,649	-	-	-	-	-	-	-	**11,149**
3. Chrome liquor storage tank cost(C_{ST})	52,500	-	-	-	-	-	-	77,569	-	-	-	-	-	-	-	**130,069**
4. Chemical feed pump cost(C_{SC})	80,000	-	-	-	-	-	-	118,200	-	-	-	-	-	-	-	**198,200**
5. Electricity uses cost(C_{SE})	670	697	725	754	784	815	848	882	917	954	992	1,031	1,073	1,116	1,160	**13,416**
6. Water uses cost(C_{SW})	162	168	175	182	190	197	205	213	222	231	240	249	259	270	281	**3,244**
7. Piping cost(C_{SP})	46,607	-	-	-	-	62,458	-	-	-	-	79,712	-	-	-	-	**188,777**
8. Portable pH meter cost(C_{SB})	10,000	-	-	-	-	-	-	14,775	-	-	-	-	-	-	-	**24,775**
9. Labor cost(C_{SL})	21,000	22,470	24,045	25,725	27,531	29,463	31,521	33,726	36,078	38,598	41,307	44,205	47,292	50,610	54,159	**527,730**
10. Sulfuric acid cost(C_{SS})	26,144	27,190	28,277	29,409	30,586	31,809	33,080	34,403	35,781	37,211	38,698	40,249	41,857	43,532	45,274	**523,500**
11. Maintenance cost(C_{SM})	14,708	15,296	15,908	16,545	17,207	17,895	18,610	19,354	20,129	20,934	21,771	22,643	23,548	24,490	25,470	**294,509**
Total actual cost (C)	**376,291**	**65,821**	**69,130**	**72,615**	**76,297**	**142,638**	**84,264**	**483,071**	**93,127**	**97,927**	**182,720**	**108,378**	**114,028**	**120,018**	**126,343**	**2,212,668**
Total present cost ($C_{8\%}$)	**348,408**	**56,429**	**54,876**	**53,372**	**51,928**	**89,890**	**49,168**	**261,003**	**46,591**	**45,360**	**78,368**	**43,037**	**41,928**	**40,866**	**39,836**	**1,301,060**

6.0 Pareto Analysis

From the system total cost that consists of the five functional costs, the add MgO control acidity and stir function cost and the add sulfuric acid control acidity and stir function cost are the two high cost contributors as illustrated by figure 10. Table 6 shows the present cost, using 8% discount rate, for each function as 2,164,125 baht and 1,301,060 baht, respectively. These figures are calculated as 52.56 % and 31.60 % of the system total cost, respectively. To reduce the total system cost effectively, one needs to look at these high-cost contributors and find a way to reduce cost.

6.1 High-cost contributors

Add MgO control acidity and stir function cost:

This function cost is made up of eleven element costs that are prioritized in figure 11. From figure 11, the high-cost contributors for this function cost are MgO cost, maintenance cost, chrome treatment tank cost and labor cost.

MgO cost - This cost is calculated by multiplying the amount of MgO use per year by its price. The product is the cost of MgO per year. The total MgO cost for 15 years is calculated by adding up MgO cost per year with 4% inflation rate taken into account. The total MgO cost is 1,456,904 baht. The amount of MgO use per year is a fixed number that cannot be decreased because it is already the optimal amount, presently, used in order to best treat the wastewater according to the study of the feasibility of chromium recovery process from tanning wastewater in Thailand. New supplier for the Magnesium oxide is not considered here due to the lack of information available. Future development of this wastewater treatment method which uses less magnesium oxide in the treatment process is suggested.

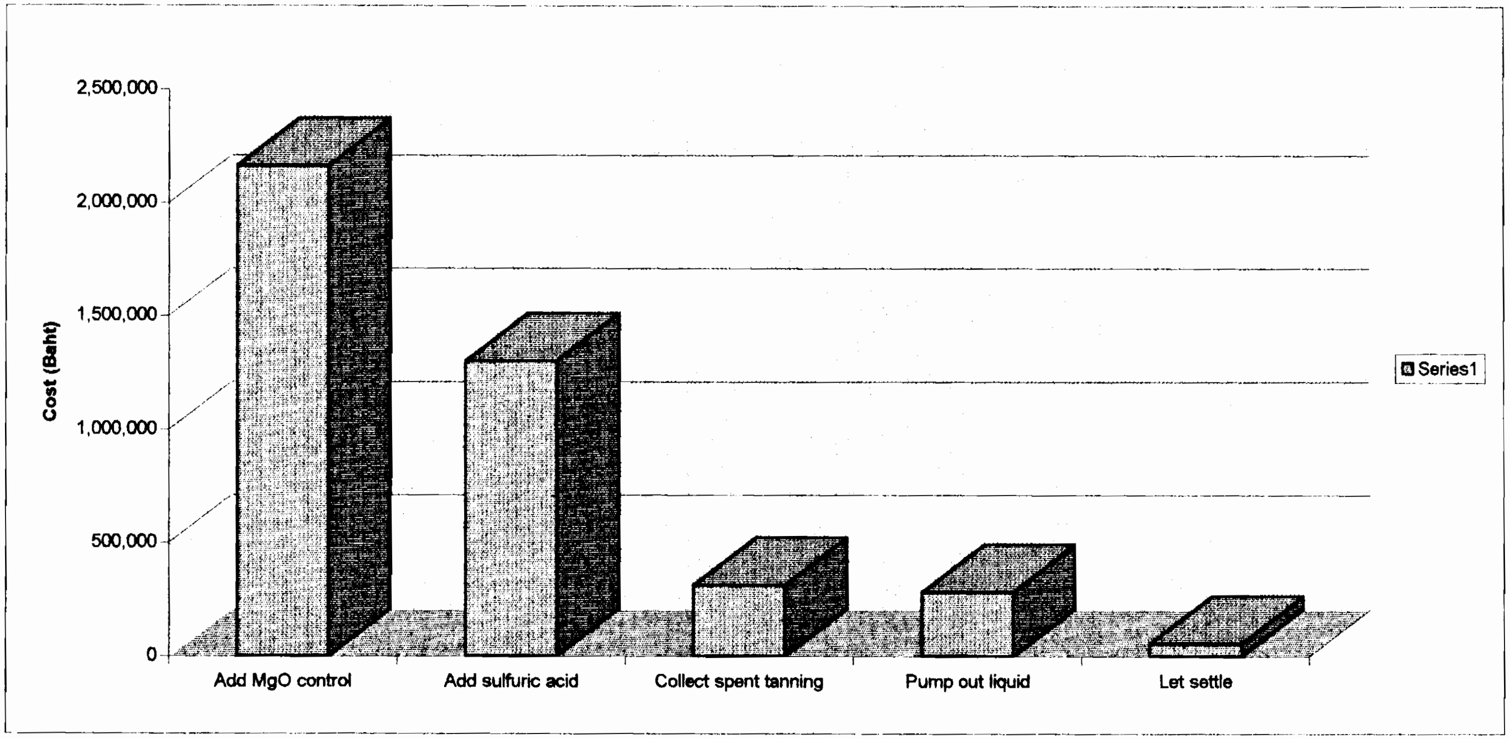

Figure 10 - Chrome Recycling Process Function Costs

TABLE 6 SYSTEM LIFE-CYCLE COST ALLOCATION

Program Activity	Function cost (Baht)	Percentage of total cost (%)
1. Collecting spent tanning liquor function costs(C_C)	314,285	7.63
2. Add MgO control acidity and stir function costs(C_M)	2,164,125	52.56
3. Let settle function costs(C_L)	55,156	1.34
4. Pump out liquid on top of chrom layer function costs(C_P)	282,876	6.87
5. Add sulfuric acid control acidity and stir function costs(C_S)	1,301,060	31.60
Total present cost($C_{8\%}$)	**4,117,502**	**100**

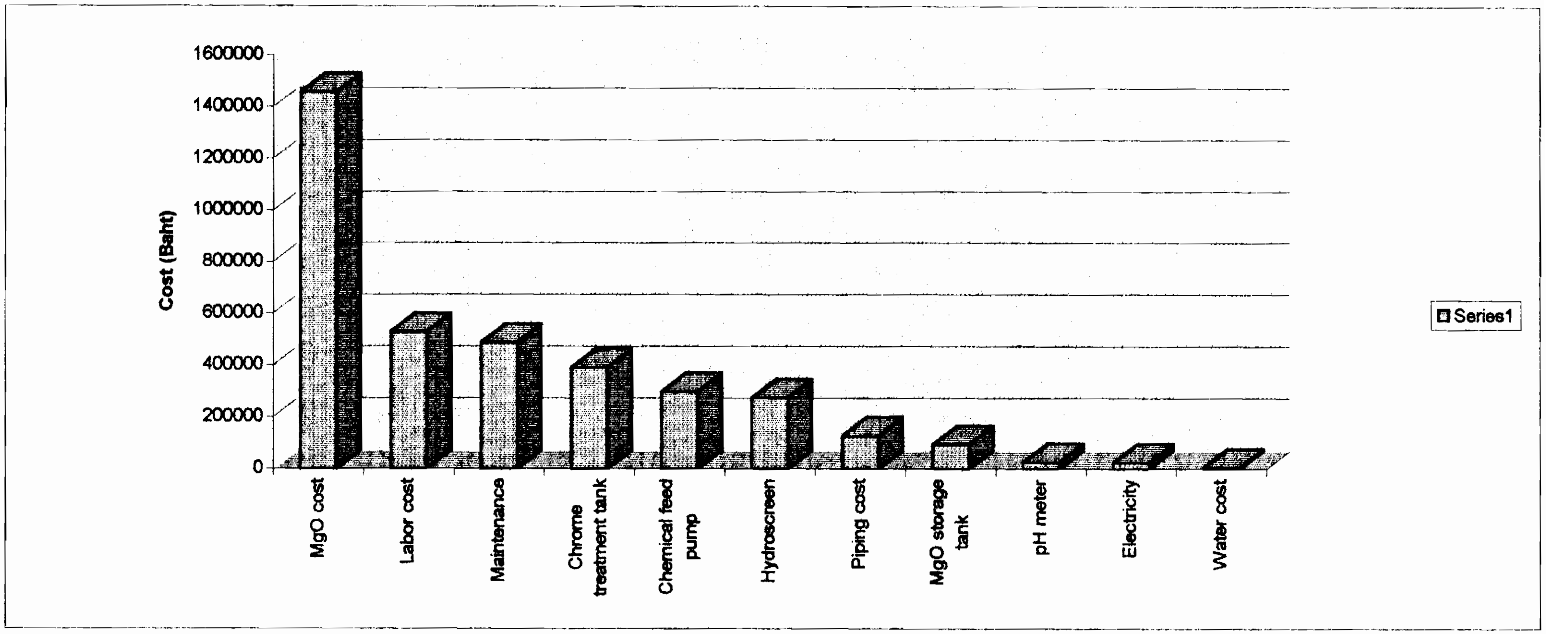

Figure 11 - Add MgO Control Acidity & Stir Function Cost Contributors

Maintenance cost - This cost is the combination of maintenance expense on chrome treatment tank & mixer (3% of its acquisition cost), chemical feed pump (10% of its acquisition cost), hydroscreen (5% of its acquisition cost), MgO storage tank & mixer (3% of its acquisition cost) and piping (3% of its acquisition cost). This includes the cost of equipment, labor, and utilities used in the maintenance actions associated with each of the system component. The cost can be reduced if fewer maintenance actions are required. To reduce maintenance action, more reliable components here are needed. However, more reliable components usually means higher acquisition costs. Acquiring more reliable components will increase the function cost here which is offset by the lower maintenance cost. Therefore, acquiring more reliable components here is not recommended.

Chrome treatment tank & mixer cost - This cost is a necessary acquisition cost that is chosen not to be eliminated in the new design.

Labor cost - The labor cost is for a single worker with organizational level skills. Therefore, this cost cannot be decreased further. Although, automation can decrease or eliminate the labor cost, but the cost of automation would definitely exceed the low labor cost of the workers in Thailand.

Add sulfuric acid control acidity and stir function cost:

This cost is made up of eleven elemental costs that are prioritized according to their contribution as shown in the figure 12. The high-cost contributors of this function are sulfuric acid , labor , chrome dissolution tank and mixer , and maintenance.

Sulfuric acid cost - this cost can be calculated the same way as MgO cost is calculated. It is also the lowest possible cost attainable, presently, for treating the wastewater effectively. New supplier for the sulfuric acid is not considered here due to the lack of information available. Future development of this wastewater treatment method which uses less of sulfuric acid is suggested.

Labor cost - this cost is the same as the labor cost described in the add MgO control acidity and stir function.

Chrome dissolution tank & mixer cost - this cost can be eliminated totally by using the chrome treatment tank and mixer in place of the chrome dissolution tank and mixer. The disposal cost for the chrome dissolution tank and mixer is visible here, but it can be offset by the amount of money acquired from selling the scrap. The chrome treatment tank and mixer cost is already stated in the "add MgO control acidity and stir" function.

Maintenance cost - this cost is the combination of maintenance expense on chrome dissolution tank and mixer (3% of its acquisition cost), chemical feed pump (10% of its acquisition cost), chrome liquor storage tank (3% of its acquisition cost), sulfuric acid storage tank (3% of its acquisition cost), and piping (3% of its acquisition cost). This function maintenance cost will be decreased when eliminating the chrome dissolution tank and mixer and the chrome liquor storage tank thus eliminating their maintenance cost. The maintenance cost for piping will also be decreased as fewer pipes are needed to connect the tanks.

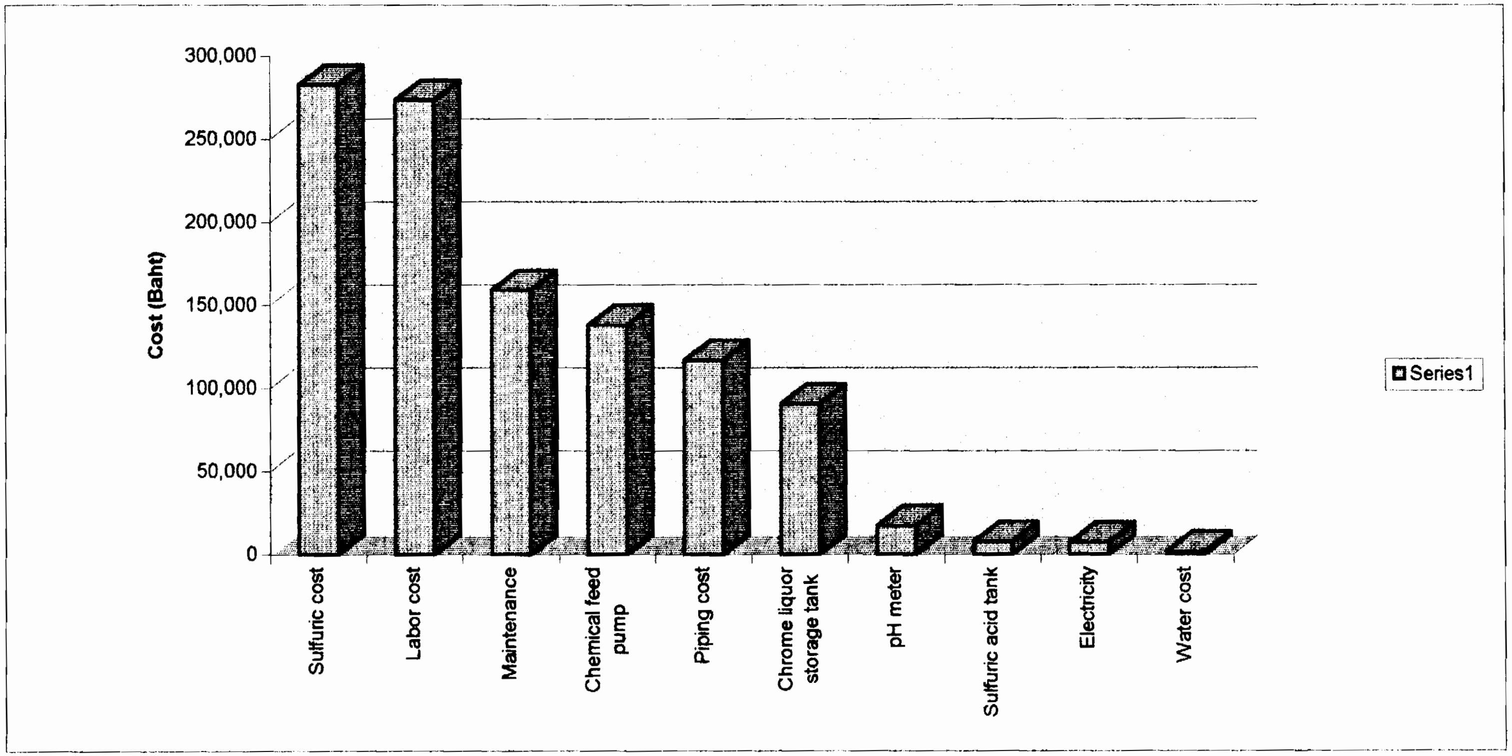

Figure 12 - Add Sulfuric Acid Control Acidity & Stir Function Cost Contributors

6.2 Changes in design

As the high-cost contributors for the total system are identified, one seeks to determine cause-and-effect relationship, propose design improvements, and reduce the overall system cost. From the analysis above, the chrome dissolution tank and mixer can be eliminated, a high cost contributor of the add sulfuric acid control acidity and stir function cost, without affecting the system performance. However, when evaluating the design further, the chrome liquor storage tank is a system component that also can be eliminated, although not a high-cost contributor. When the two tanks stated above are eliminated, there will not be any need for the screw pump that pumps in and out solution from the chrome dissolution tank. As a result, the new system design will have all the system elements except for the two tanks and the screw pump. The changes in design do not affect the system's performance because the system does not operate continuously. The system treats the chrome wash wastewater by the tank; therefore, with the system's old design, all tanks in the system have some idle time. The redesign system maximizes the tank usage and saves the component acquisition costs. The new design of the system can be seen in figure 13.

7.0 New Design Life-Cycle Cost Analysis

The life-cycle cost of the new chromium recycling process system design is made up of the same function costs as the old design as shown earlier in the CBS, figure 9 page 22. The differences between the two designs are in the "add sulfuric acid control acidity and stir" function and the "pump out liquid on top of chrome layer" function. In these functions, the costs that will be eliminated are the chrome dissolution tank & mixer cost, the chrome liquor storage tank cost and screw pump cost. Additionally, the costs that are reduced in these functional areas are the piping cost, maintenance cost, and electricity uses cost.

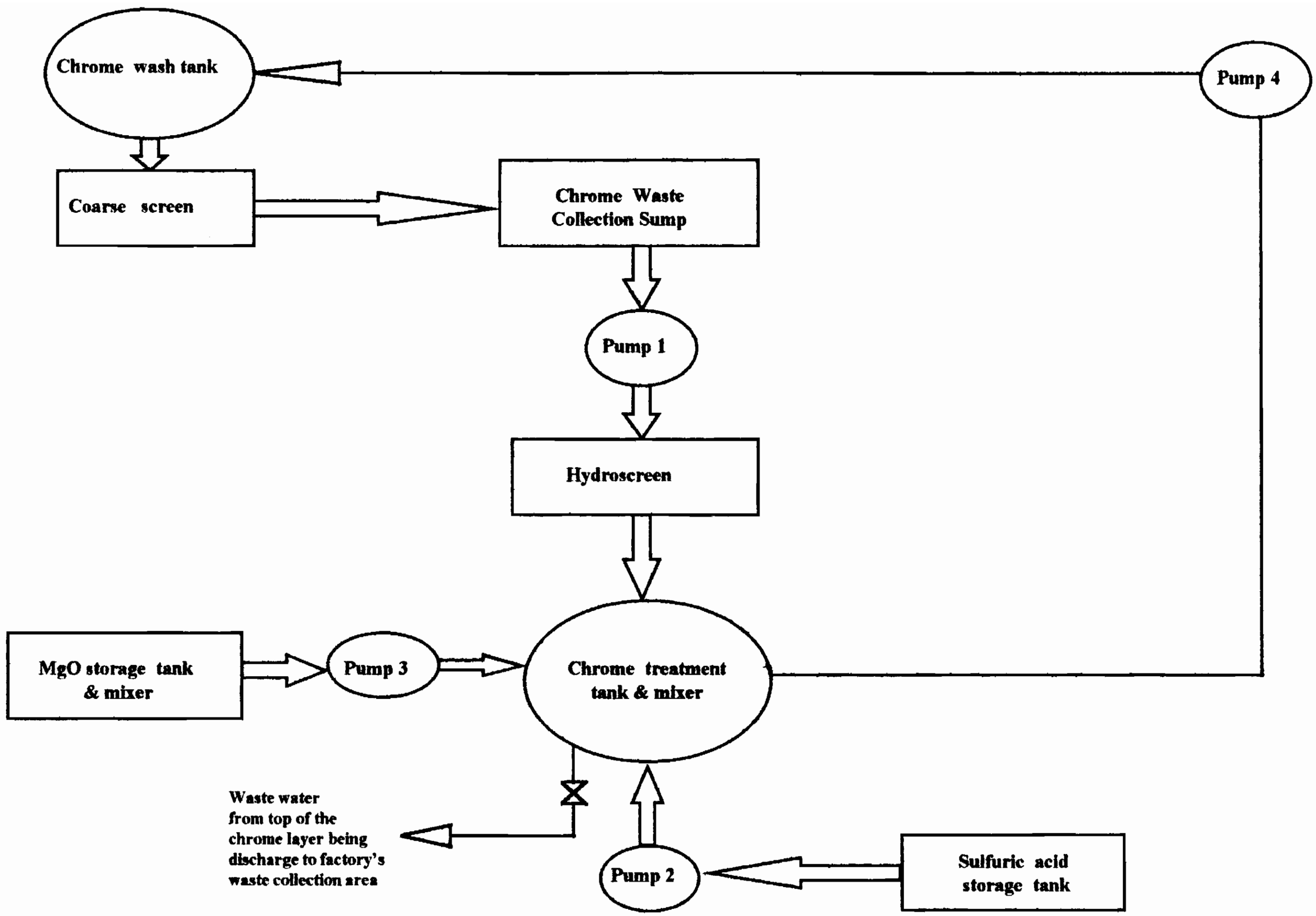

Figure 13 - New System Design

7.0.1 Add sulfuric acid control acidity and stir function cost

Other elements in this function are the same as the old design except the following:

1. Chrome dissolution tank & mixer cost - this acquisition cost can be eliminated totally. The total chromium recycling system life-cycle cost reduction from this elimination is 206,903 baht in present value.

2. Chrome liquor storage tank cost - this acquisition cost can be totally eliminated totally also. The cost reduction as the result of this elimination is 90,520 baht in present value.

3. Piping cost - as the result of the elimination of the two tanks above, fewer pipes are needed and thus piping cost is reduced. The piping cost reduction is 81,694 baht in present value.

4. Maintenance cost - the maintenance expense on the chrome dissolution tank and mixer and chrome liquor storage tank is eliminated. Moreover, the maintenance expense on the pipes is reduced as fewer pipes are needed. Therefore, the maintenance cost in this function of the new design system will consist of expenses on the following equipment:

Sulfuric acid storage tank	- 3% of its acquisition cost
Chemical feed pump	- 10% of its acquisition cost
Pipes	- 3% of its acquisition cost

5. Electricity uses cost - less electricity is used as a result of the elimination of the mixer in the chrome dissolution tank. The cost is based on the following:

Chemical feed pump uses 0.37 kW x 0.5 hr = 0.185 kW-hr

Electricity/ton of raw hide = 0.185/10.76 = 0.0172 kW-hr/ton of raw hide

Electricity cost per year = 0.0172 x 10.76 ton of raw hide x 300 work days x 2.40 baht / kW-hr

= 133 baht per year

This yearly cost accumulated for 15 years will determine the total electricity cost for this function. The present value total electricity cost is 1,437 baht. That is a saving of 5,805 baht over the old design.

6. Installation and test cost - labor and equipment used in installing and testing the new design is considered here. This is a little one-time cost currently costing 8,000 baht because only two tanks and a pump are disconnected, and the reconnection of the new design is a simple task.

7. Disposal cost - the tanks and pipes can be sold as scrap for its metal which currently generates income of 1,000 baht.

The new add sulfuric acid control acidity and stir function cost summary is in table 7. The specific saving for each of the cost as the result of changes is shown in table 8.

TABLE 7 NEW DESIGN ADD SULFURIC ACID CONTROL ACIDITY AND STIR FUNCTION COST SUMMARY

	Cost by Program Year (Baht)															
Program Activity	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15	Total
1. Sulfuric acid storage tank (C_{SA})	4,500	-	-	-	-	-	-	6,649	-	-	-	-	-	-	-	**11,149**
2. Chemical feed pump cost (C_{SC})	80,000	-	-	-	-	-	-	118,200	-	-	-	-	-	-	-	**198,200**
3. Electricity utilization cost (C_{SE})	133	138	144	150	156	162	168	175	182	189	197	205	213	221	230	**2,663**
4. Water uses cost (C_{SW})	162	168	175	182	190	197	205	213	222	231	240	249	259	270	281	**3,244**
5. Piping cost (C_{SP})	13,982	-	-	-	-	18,736	-	-	-	-	23,909	-	-	-	-	**56,627**
6. Portable pH meter cost (C_{SB})	10,000	-	-	-	-	-	-	14,775	-	-	-	-	-	-	-	**24,776**
7. Labor cost(C_{SL})	21,000	22,470	24,045	25,725	27,531	29,463	31,521	33,726	36,078	38,598	41,307	44,205	47,292	50,610	54,159	**527,730**
8. Sulfuric acid cost(C_{SS})	26,144	27,190	28,277	29,409	30,586	31,809	33,080	34,403	35,781	37,211	38,698	40,249	41,857	43,532	45,274	**523,500**
9. Maintenance cost(C_{SM})	8,554	8,896	9,252	9,622	10,007	10,408	10,823	11,256	11,707	12,175	12,662	13,169	13,695	14,243	14,813	**171,282**
Total actual cost (C)	**164,475**	**58,862**	**61,893**	**65,088**	**68,470**	**90,775**	**75,797**	**219,397**	**83,970**	**88,404**	**117,013**	**98,077**	**103,316**	**108,876**	**114,757**	**1,519,170**
Total present cost ($C_{8\%}$)	**152,287**	**50,463**	**49,131**	**47,840**	**46,601**	**57,206**	**44,228**	**118,540**	**42,010**	**40,949**	**50,187**	**38,946**	**37,989**	**37,072**	**36,183**	**849,632**

TABLE 8 ADD SULFURIC ACID CONTROL ACIDITY AND STIR FUNCTION COST COMPARISON

Program Activity	Old design cost(Baht)	New design cost(Baht)	Saving(Baht)
1. Chrome dissolution tank and mixer cost(C_{SD})	206,903	0	206,903
2. Sulfuric acid storage tank(C_{SA})	7,759	7,759	0
3. Chrome liquor storage tank cost(C_{ST})	90,520	0	90,520
4. Chemical feed pump cost(C_{SC})	137,935	137,935	0
5. Electricity uses cost(C_{SE})	7,242	1,437	5,805
6. Water uses cost(C_{SW})	1,751	1,751	0
7. Piping cost(C_{SP})	116,702	35,008	81,694
8. Portable pH meter cost(C_{SB})	17,242	17,242	0
9. Labor cost(C_{SL})	273,519	273,519	0
10. Sulfuric acid cost(C_{SS})	282,538	282,538	0
11. Maintenance cost(C_{SM})	158,949	92,442	66,507
12. Installation & test cost	-	8,000	-8,000
13. Disposal cost	-	-1,000	1,000
Total present cost($C_{8\%}$)	**1,301,060**	**856,632**	**444,428**

7.0.2 Pump out liquid on top of chrome layer function cost

Other elements in this function are the same as the old design system except for the following:

1. **Screw pump cost** - this cost is eliminated, resulting in a life-cycle cost reduction of 137,936 baht in present value.

2. **Electricity uses cost** - this cost is also eliminated since the only equipment that uses electricity in this function is the screw pump which has been eliminated. As the result, the reduction in the system life-cycle cost is 14,546 baht in present value.

3. **Maintenance cost** - this cost is reduced when the screw pump is eliminated, and the only component needing maintenance is the pipes. The maintenance cost of it is 3% of its acquisition cost.

4. **Disposal cost** - this is not a cost but an income. The screw pump can be sold as the pump. This is a one-time income which generates 20,000 baht.

A revised cost summary of this function is shown in table 9. The specific saving as a result of changes is shown in table 10.

TABLE 9 NEW DESIGN PUMP OUT LIQUID ON TOP OF CHROME LAYER FUNCTION COST SUMMARY

	Cost by Program Year (Baht)															
Program Activity	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15	Total
1. Piping cost(C_{PP})	15,536	-	-	-	-	20,820	-	-	-	-	26,571	-	-	-	-	62,927
2. Maintenance cost(C_{PM})	466	485	504	524	545	567	590	613	638	663	690	717	746	776	807	9,331
Total actual cost (C)	16,002	485	504	524	545	21,387	590	613	638	663	27,261	717	746	776	807	72,258
Total present cost ($C_{8\%}$)	14,816	416	400	385	371	13,478	344	331	319	307	11,692	285	274	264	254	43,938

TABLE 10 PUMP OUT LIQUID ON TOP OF CHROME LAYER FUNCTION COST COMPARISON

Program Activity	Old design cost (Baht)	New design cost(Baht)	Saving(Baht)
1. Screw pump cost(C_{PS})	137,936	0	137,936
2. Piping cost(C_{PP})	38,902	38,902	0
3. Electricity uses cost(C_{PE})	14,546	0	14,546
4. Maintenance cost(C_{PM})	91,492	5,036	86,456
5. Disposal cost	-	-20,000	20,000
Total present cost($C_{8\%}$)	**282,876**	**23,938**	**258,938**

7.1 Effect from changes in design

After redesigning the chromium recycling process system, functional costs for the five functions are calculated again. From table 11, the new "Pump out liquid on top of chrome layer" function cost and the new "Add sulfuric acid control acidity and stir" function cost are different from the old ones. The rest of the function costs remain the same. The cost reduction in the "Pump out liquid on top of chrome layer" function of 258,938 baht, present value, and the cost reduction in the "Add sulfuric acid control acidity and stir" function of 444,428 baht, present value, are the results of the redesign. Again from table 11, the system life-cycle cost of the new design system is 3,414,136 baht. This is a saving of 703,366 baht over the old design considering 15 years of system operation.

8.0 Conclusion

The application of life-cycle cost analysis methods for the purpose of identifying high- cost contributors for a system represents an excellent approach, leading to the possible initiation of changes for improvement and subsequent reduction in total system cost.

This project illustrated this approach by identifying high-cost areas, evaluating cause-and-effect relationships, and resulting in a redesign of the Chromium Recycling Process as part of a tannery operation. Accomplishing these steps on a continuing basis should result in an effective "continuous process improvement" program for the tannery.

TABLE 11 NEW DESIGN SYSTEM LIFE-CYCLE COST ALLOCATION

Program Activity	Function cost (Baht)	Percentage of total cost (%)
1. Collecting spent tanning liquor function costs(C_C)	314,285	9.21
2. Add MgO control acidity and stir function costs(C_M)	2,164,125	63.39
3. Let settle function costs(C_L)	55,156	1.62
4. Pump out liquid on top of chrom layer function costs(C_P)	23,938	0.70
5. Add sulfuric acid control acidity and stir function costs(C_S)	856,632	25.09
Total present cost($C_{8\%}$)	**3,414,136**	**100**

To identify the high-cost contributors, one needs to come up with what sort of data to use, and if it can be found. If one can not find the data, he/she has to come up with the new sort of data which also represents the same information as the old data. Once these high-cost contributors were identified, they are evaluated to see if they can be reduced or eliminated. The chrome treatment tank and mixer and the chrome dissolution tank and mixer are also two of the high-cost contributors studied to cut their costs. In this project, there were many idle times associated with the three main tanks, the chrome treatment tank, the chrome dissolution tank, and the chrome liquor storage tank. This indicates that the tanks are underused, and possible elimination of some tanks is applicable. The two later tanks of the three are eliminated as the result of the redesign. All the functions of the two tanks are transferred to only the chrome treatment tank and mixer which will operate the tank at fuller capacity. The result was a significant system total cost reduction. Although the result may not be as accurate as it could have been due to the some data inadequacies, the validity of the result still stands. As the result of the initiation of this continuous improvement process in the future, the total cost of the system will be low enough to attract everyone in the tanning business.

9.0 Future Recommendations

The future recommendations for this project are:

- Establish a better data collection, analysis, and improvement capability to enhance visibility and being able to better "target" future opportunities for cost reduction. The area that needs better data and visibility is maintenance and support. More specific data concerning the maintenance costs associated with each system component will be helpful in trying to reduce the overall cost. Specifically, for each component, how much maintenance actions are needed, and what fraction of the maintenance cost is allocated to maintenance personnel, maintenance material, and maintenance equipment.
- Application of process to this tannery operations in the future.
- Application of process to other tannery operations in Thailand (and the world).

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