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Down-costing of Tannery Waste Water Chromium Recovery Plants in Pakistan: A Case Study of Techno-Economic Evaluation of a Chromium Recycling Plant

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Abstract

Techno-economic evaluation of the Chromium Recycling Plant installed at Riaz Tanneries Kasur Pakistan was conducted as a case study in context of down-costing of chromium recovery plants in Pakistan. The primary data was collected taking responses against a questionnaire that was e-mailed to the executives of the tannery under study and subsequent conducting of interviews with the concerned officials. The collected data was computed, project cost designed and subsequently appraised to determine the Net Present Value (NPV) and Benefit to Cost (B/C) Ratio of the Project applying the standard discounted cash flow techniques. The Pay Back Period (PBP) of the project was also determined.

The evaluation presented B/C Ratio of 4.67, positive NPV of US$80,864 and payback period 100 days if the price of the recycled basic chromium sulfate is taken at par with that of fresh chemical from the market and the payback period was 245 days if the price of the recycled chemical is considered equal to half of the market price. The indices successfully meet the acceptance criteria laid down under the project appraisal rules. Thus, the installation of the chrome recycling plant at Riaz Tanneries is economically viable and environmentally beneficial. However, a number of external factors hamper the efficiency of recycling technology.

Key Words: Techno-economic • Chromium • Recovery • Tanneries* Kasur

1. Introduction

Recycling of chromium to reduce its content in tannery wastewater liberated in environment is a major problem these days. Chromium, if liberated in the environment causes a number of physiological disorders in general and nervous disorders in particular. Approximately, 30% of the chromium used in tanning process is taken up by the hides for their transformation into leather while 70% remains dissolved and enters waste water runoffs in the conventional chrome tanning practice (Arrafay Labs, 2003).

In recent years, there has been an enormous concern over the expansion of the leather sector in different countries as it has resulted in substantial pressure on the environment because the tannery effluent affects the biological health of the ecosystems. Leather tanning industry has been even banned in many countries on the grounds of the danger it poses to the biological health. On the contrary, it is expanding in Pakistan for the reason that tanning industry is one of the major contributors to foreign exchange earnings and has added value to the Pakistan's exports. It holds 7% share in total foreign exchange earnings of Pakistan. This is the rosy side of the picture that presents tanning as a blessing for the developing countries trade balance and fiscal budgeting. On the other hand; it is also a source of a lot of annoyance as it produces a large number of solid, liquid and gaseous pollutants that impose high social costs in terms of negative externalities.

Chrome recovery and recycling is a common practice in Pakistan. Chrome recovery is accomplished through alkali precipitation of Cr as chromium hydroxide and dissolution of precipitate in sulfuric acid to recover chromium as basic chromium sulfate. Chrome recycling differs from chrome recovery as it involves single treatment of tannery effluent with sulfuric acid and subsequent recycling of process water.

Pakistan's leather industry has gained prominence over a period of time since 1947 mainly due to three reasons: significant foreign exchange earnings; government grants and rebates to boost up leather industry; and rigorous environmental laws set by the developed countries. There were only a few of tanneries in Pakistan after the partition of India and majority of the skins and hides were exported. Today, the leather industry of Pakistan has earned an identity of its own both at home and abroad as an important sector of national economy local that delivers an excellent quality of leather.

Since indication of the need for chrome recycling and recovery, a number of researchers have carried out research focused on methods of accomplishing these processes. Davis and Scroggie (1973) recognized a scientific basis for efficient chrome recycling. Voice et al (1988) investigated opportunities for recovery of chromium (III) in cattle hide tanneries and concluded that direct reuse of spent tanning liquors provided the most effective means of recovering soluble chromium. Ludwick and Bulian (2001) reported after a UNIDO study that chrome utilization can be increased in three ways: high-exhaustion chrome tanning; direct recycling of spent floats and chrome recovery/reuse. In the last decade many studies such as by Shen et al (2001) Freitas (2006) and others dealing with different facets of the problem have appeared.

In Pakistan, Khan (2004, 2007) carried out techno-economic evaluation of Chrome Recovery Pilot Plant installed at Kasur and reported that it was far from the criteria of economic viability. The study signaled to frame a pilot project,"Down-costing of Chrome Recovery /Recycling Plants in Pakistan". The piece of work being presented here was planned and carried out as a component of the said Pilot Project to assess how far the recycling plant designed and implemented in Riaz Tanneries Kasur is technically sound and economically viable.

2. Methodology of Research

2.1 Collection of Data

To collect data a questionnaire was designed dispatched to the officials concerned and responses received. Visits to Riaz Tanneries were organized to observe chromium treatment plant in action. Both telephonic and face-to-face interviews were conducted to gather data regarding benefits, methods and technology involved in chromium recycling.

2.2 Data Analysis

The data were computed and project cost designed. Discounted cash flow techniques used by the Asian Development Bank (ADB, 2001 and 2003) in appraisal of projects in South Asia were applied for the appraisal of the plant under study. Both expenditure and returns were projected over ten years that was the project life and discounted to the base year (2000 – 2001) at 10% discount rate. NPV, B/C Ratio and PBP were computed and

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these indicators were compared with those reported by some workers who had carried out similar studies in Pakistan.

The project was also subjected to sensitivity analysis to examine the way in which output varies with alterations in input parameters such as discount rate and project life. The basic principle of sensitivity analysis is that one of the parameters is varied keeping others constant to see its impact on NPV and B/C Ratio. To assess the impact of variation in life, the basic discount rate of 10% is kept constant sand project life varied from 10 to 5, 15 and 20 years. Similarly, to check the impact of change in discount rate from 10 to 5, 15 and 20%, project life was kept constant as 10 years. All reevaluations were done as were done in primary project described before.

2.3 Presentation of Results

The information regarding the construction, working and operation of the plant was reported as descriptive research, while the results of cost analysis were applied to interpret the technical soundness and the economic viability of the plant.

2.4 Cost Analysis

The basic assumptions for the project framework and computation of benefits and costs are given in Appendix 1.

2.4.1. Initial Fixed Investment

It included the cost of land, building, machinery and equipment, laboratory equipment and pre-production expenditure as computed in Appendix 1.

Total Initial Fixed Investment =

$ (833.33 +416.66 +333.33 + 2083.33 +333.33 + 83.33) = $4083

2.4.2 Operating Cost

The operating cost has been computed in Table 1 and 2(App.2)

2.4.2.1 Expenditure in the Year 0

Initial fixed Investment = $4083

Operating Cost = Nil

Total Expenditure = $4083

2.4.2.2 Expenditure in Future Years

Assumptions are given in Appendix 1 and the computation displayed in Table 1 (App. 2)

2.4.2.3 Total Operating Cost Discounted to the Base Year

It is computed in Table 2(App. 2) = $ 17,978

2.5 Benefits

For the calculation of the benefits, an average of three runs of tannery float on three different dates at different points of time was taken into account to average chromium recycled. The amounts of chromium used per day, chromium absorbed during the process of chrome tanning and chromium recycled are computed in Appendix 1.

2.5.1 B/C Ratios, NPV and PBP

The values are computed in Appendix1.

2.6 Different Scenarios for Plant Efficiency

2.7 The technical experts engaged by the PTA pointed out an efficiency variation from 40 to 60% while, the plant at Riaz Tanneries was claimed to be 90 to 100% efficient. The calculation of benefits per annum and PBP for different efficiencies from 40 to 90 % is computed in Table 3 (App.2).

3. Results and Discussion

The results are presented in two parts. The first part is purely a descriptive research that presents observations on the setup, technology, and functioning of the plant and the second presents the results of the data processed in the cost analysis section.

3.1. Riaz Tanneries, Kasur

Riaz Tanneries is a leather and leather garments manufacturing establishment. It produces a vast array of leather related products including raw to finished leather for shoes and jackets. It has two offices: head office and a garment unit. Riaz Tanneries is a member of Kasur Tannery Water Management Authority (KTWMA), a world fame organization in the leather sector of Pakistan. It is one of the pioneers in the environmental control of tannery water activities. It has a profound existence on the international level. As a producer and manufacturer of leather, it exports 80% of its processed leather and the

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remaining 20% is kept for local sale. The tannery's scale of production is 232, 258 m^2 each year and 1,394 m^2 daily.

3.2. Technology of Chrome Recycling Process

3.2.1. Principle of the Process: The procedure of recycling is straightforward. The tannery float is treated with sulfuric acid at a controlled pH. The reaction translates into the formation of basic chromium sulphate originally used for chrome tanning. The treated float is stored, fortified with fresh basic chromium sulfate per requirement and recycled.

3.2.2. Operations and Sub-processes: The chrome recycling plant at Riaz Tanneries is a simple, locally manufactured unit. The sub-processes involved in the recycling of chromium are shown in Fig. 1.

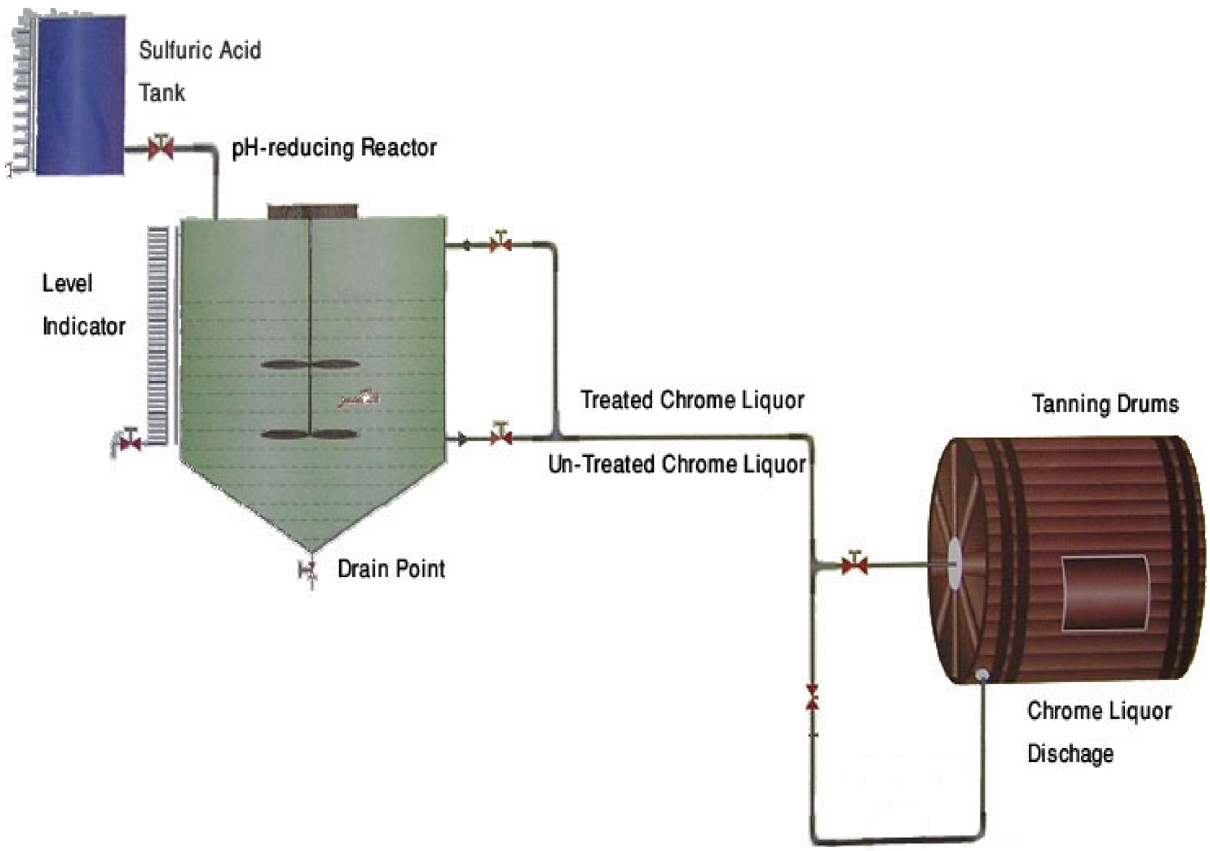

Fig.1: The Sub Processes Involved in the Recycling of Chromium (Courtesy-Riaz Tanneries).

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- **Transport of Chrome liquor to the Plant:** Chrome liquor from the tanning drum is transported to a reactor through rubber pipes that constitute extension of the main tannery drainage line.

- **Sulfuric Acid Tank:** It is a steel tank that stores sulfuric acid of requisite strength.
- **Reactor:** The reactor is a steel tank in which spent tanning liquor's treatment is carried out. The chrome content of liquor is checked. A calculated volume of sulfuric acid is transferred from the sulfuric acid tank to adjust the pH at 2.88 subsequently controlled at this value. The reactor also functions to lower down the pH. It is equipped with a stirring device to ensure thorough mixing.
- **Recycling:** The float is recycled to the tanning drum and fresh chrome is added to restore the desired level of chrome content in the tanning liquor used for tanning of leather. The drain point releases unwanted deposits and liquid not worth recycling. Therefore; the left over leather fiber and un-dissolved impurities enter water bodies in the form of effluents through the local drainage system.

3.3 Results of the Cost Analysis

Unfortunately, not much work on cost analysis has been undertaken in Pakistan to assess the effectiveness of chrome recycling by application of project analysis techniques. Some workers have recently done this exercise on techno-economic disposal of different industrial effluents including tannery waters (Khan, 2004). Therefore, lack of work in this field of Environmental Economics related to chromium recycling limits our comparison of results to the results of predecessors in this field of study. However, we can compare some of our findings and opinions with some foreign researchers.

3.3.1. Benefit /Cost Ratio and NPV

Benefit to Cost ratio is an important criterion for grading a project as non-profitable, profitable or socially acceptable. The decision rule is that if it is more than 1, the project is profitable and thus acceptable and if it is less than one, it is non- profitable (Khan, 2004). The acceptance criterion based on NPV of a Project is that the project is acceptable if NPV is positive. If it is negative, then project is rejected provided it does not fall in the category of social obligations. Having mentioned the decision rule for B/C

Ratio and NPV, the results now can be interpreted with reference to the project appraisal criteria. Khan's (2004, 2008) reported cost analysis results of evaluation of an imported chromium recovery plant at Kasur as B/C ratio of 0.5 and a negative NPV of $238,486. Both values led to the rejection of the project when compared to the standard criteria. However, here the cost analysis resulted in B/C of 4.67 and a positive NPV of $ 80,864. Both indices qualify acceptance criteria and thus the installation of the chromium recycling plant at Riaz Tanneries is clearly feasible on financial as well as environmental grounds.

3.3.2. Payback Period Results

According to the payback method shorter is the PBP, earlier is the recovery of the investment in a project. Here PBP results show that recovery is very quick, that is, within 100 days if the price of recycled chromium is considered at par with that of the purchased chromium and 241 days if it is considered as half of the purchased chromium which makes the plant under study tremendously cost effective and financially viable. Here, PBP is poles apart from Khan's extremely unfavorable PBP of 36 years for imported recovery plant installed by KTWMA. The results can be compared with those of Voice (1988) who also concluded that direct reuse of spent tanning liquors provided the most effective means of recovering soluble chromium from this source.

2.8 3. Different Scenarios for Plant Efficiency

Table 3 indicates how benefits per annum and PBP change at various levels of chromium recycling plant capacity utilization. It can be seen that if the efficiency level increases, benefit/cost ratio increases and payback period decreases. Therefore, higher the efficiency of chrome recycling plant, more cost effective and competent the plant will be in terms of savings and recovery.

3.3.4. Sensitivity of the Project

The integrated results of sensitivity analysis are presented in Table 4 and 5.

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Table 4: NPV & B/C at different discount rates of 5%, 10%, 15% & 20% (US $).

Disc. Rate	5%	10%	15%	20%
Annuity	7.72173	6.14457	5.01877	4.19247
P.V of Benefits	16,737.50*7.72173 +208.33*0.613913= 129,370	102925	16,737.50*5.01877+ 208.33*0.247185 = 84053	16,737.50*4.19247+ 208.33*0.161506 = 70,205
P.V of Costs	23,151.53+4,083.33= 27,235	22,061	14,356+4,083= 18,439	12,748+4,083 =15,831
NPV	102,135	80,864	65,614	54,374
B/C	4.80	4.67	4.56	4.43

Table 5: NPV and B/C at discount rate of 10% for 5, 10,15 and 20 years (US$)

Years	5 Years	10 Years	15 Years	20 Years
Annuity)	3.790787	6.14457	7.606080	8.513564
P.V of Benefits	63,578	102,925	127,357	142,527
P.V of Costs	9,688 +4,083 = 13,772	22,061	25,248+4083 =29,832	31,842+4083 = 35,925
NPV	49,805	80,864	97,525	1,056602
B/C	4.62	4.67	4.34	3.97

Table 4 shows NPV and B/C at different discount rates at constant project life of ten year. The general trend encountered with varying discount rates is that the B/C and NPV decline with increase in discount rate. The NPV is the highest at 5% discount rate and it gradually decreases with increase in discount rate. Similarly, B/C is the highest at 5% and declines to the lowest at 20%.

Table 5 presents the changes in NPV and B/C at constant discount rate with the changing project life. The NPV tends to increase with the increase in project life. Opposite is the trend of B/C.

Up to this point merely quantitative aspects of the two plants have been focused upon: Khan's chromium recovery pilot plant (Khan, 2004, 2008) and the chromium recycling plant under study. The points of difference between the two demand a deeper insight that translates into extreme variations and significance in down costing of chromium recovery plants in Pakistan. A comparison of observations, indications and recommendations by Khan (2004, 2008) is requisite to verify his stance, cross-examine his evaluations versus techno-economic evaluation of the chrome recycling plant at Riaz Tanneries. Various aspects that take the note of the dissimilarities in the project appraisal indices are discussed below:

1. The recycling plant at Riaz Tanneries costs only US$2,083 that is very low as compared to plant evaluated by Khan costing US$66,667. It is a locally manufactured unit (Fig.1) as opposed to the other that was imported from Italy and is32 times costlier. Thus the major reason for the variation in the results of both plants is the cost. The low cost of the plant provides an edge to the recycling plant installed in Riaz Tanneries thereby drastically reducing the payback period.
2. Riaz Tanneries chromium recycling plant is installed as a part of the tannery by integrating the recycling plant with the main set up that allows for cost savings in the form of investment on purchase of land and construction of building. On the contrary, the pilot plant, in spite of being under the control of KTWMA, is installed separately at a different site in an independent building at an additional capital expenditure of US$26,667. This justifies Khan's (2004, 2008) point that the initial investment on land and building also hampers the possibility of its early recovery.
3. The services of the labor engaged in overall tanning activity have been partially diverted to run the recycling plant at Riaz Tanneries. The Plant Supervisor at Riaz Tanneries justified low cost set ups as hired labor can be switched from the main set up to the auxiliary and vice versa. Riaz Tanneries gained by optimizing upon labor utilization and thereby benefiting from reduction in operating cost.

4. Different plant technology options are available for the choice of the decision makers. The most general choice as Khan (2004, 2008) puts down is the "Core Technology" purchased either on 'turn key' basis or installed with the help of contractors on commissioning basis. An alternative choice is "Synthetic Technology" that involves the break up of the core process into sub-processes and purchase of machinery at sub-process level from local or foreign markets and its installation by the local experts, by foreign experts or by local and foreign experts as a team. Riaz Tanneries plant has a comparative advantage in this regard as it has local components that have substituted the imported components. This substitution has substantially reduced the cost of machinery. Thus, Khan's indication holds true that dramatic reduction of initial costs is possible if the technology is partially or wholly local.
5. Although the number of shifts at Riaz Tanneries is one, it follows a more flexible working routine depending on the capacity of work. Some processes require extra shifts; therefore working hours are extended. Thus, Riaz tanneries reaps economic advantages by capitalizing on time, labor savings and minimizing on cost by hiring labor that can be multi-task. The pilot plant at Kasur is running strictly on a single shift basis. If it is operated on double shift basis, other cost factors held constant, the annual cash flow may be double as a result of which, the PBP may be halved (18 and 16 instead of 36 and 33),as suggested by Khan (204, 2008). Correspondingly, if it runs on three shift basis, the payback may reduce to one third (12 or 11).
6. Riaz Tannery operates at 90% of its plant capacity; the plant's optimal capacity at which marginal cost is the lowest and returns are the highest. That is why it is also known as marginal efficiency capacity. However, the pilot plant is operating far below its capacity which means it is not properly utilizing benefits of economies of scales.

The overall analysis endorses the whole track traced by Khan (2004, 2008) for the extension of techno-economic evaluation of chromium recovery/recycling plants in down-costing context.

Although the plant at Riaz Tanneries is socio-economically justified, Riaz Tanneries is facing some difficulties in use of recycled chromium. The executives told that patches due to excess fat and color variations were evident in leather manufactured from the use of recycled chrome. Since the plant studies here is financially and environmentally sound, recommendation may be made to ensure a substantial increase in chrome utilization without compromising on quality standards. Consistency of quality in leather is essential to maintain the standard of tanned leather export earnings of Pakistan.

3 Conclusions

The major conclusion that can be drawn in commercial context is, 'Chromium recycling plant at Riaz Tanneries is technically sound, economically viable and socially acceptable'. Even if the indicators were below the decision criteria, tanners would have to take account of the negative externalities resulting from the manufacturing of leather as the project falls under the communal obligations of the tanners to dictate that they are required to process the effluent for elimination of chromium to meet the NEQS standards.

Above all, the enquiry has proved that involvement of local talent is more appropriate to plan technology in the country as it is more familiar with the indigenous environment. The Pakistan Tanners Association may be accredited for their successful attempt to down-cost chromium recovery in Riaz Tannery by installing a chromium recycling plant and should get some other model plants evaluated on the same lines to fortify the results presented here and to fortify the idea that this type of down-costing can be done in other industries of Pakistan and developing countries.

In the light of the analysis, following recommendations are made:

- Pakistan should inculcate in its collective self the spirit of standing on its own feet as its experts know national conditions and requirements better than any other. Thus, it should have confidence in its own talent and skill and should not only encourage them but also support them through thick and thin.
- The spectrum of activity should be extended to the evaluation of projects pertaining to techno-economic effluent disposal in other industries.

- The environment should be protected to the industry's highest standards. EN ISO 14001:1996.
- Pakistan should produce leather that achieves suitable performance against industry's standard tests.
- Pakistan should fortify its research and development activity for advancement in better float collection methods and more sophisticated recycling techniques that contribute to the achievement of 95 - 98 % efficiency without any loss in quality of leather.

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Appendix 1

Project Life: 10 Years

Base-Year: 2001

Evaluation Year: 2001

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Average Discount Rate in Pakistan: 10% (Average interest paid by the banks and other lending agencies.)

Starting and Closing of Financial Year: July 1 to June 30

Currency Equivalent: One US$=Pak. Rupees 60 (2008, year of study)

Initial Fixed Investment

Land:

Total Area = 20.9 m^2

Constructed Area = Installed in open

Open Space = 20.9 m^2

Total Land = 41.8 m^2

Cost of Land/ m^2 = US$19.93

Total Cost of Land = US$833.33

Building:

Cost of Construction of the Platform for Installation of Plant = US$166.67

Cost of Construction of Drainage for the Recycling Plant and Disposal of Treated Effluent = US$250

Total Cost of Building = US$ (166.67 + 250) = US$416.67

Total Cost of Electrical Equipment = US$333.33

Machinery and Equipment:

Cost of Plant Machinery and Equipment = US$2,083.33

Site Visits for Civil Works by Contractors = Nil

Sales Tax (Free of cost from NEC on basis of agreement with PTA)

Vehicles = None

Generators = None

Total Cost of Machinery and Equipment = US$2083.33

Total Cost of Laboratory Equipment = US$333.33

Pre-Production Expenditure:

Manpower = US$83.33

Consultants (Free of cost consultancy from NEC) = Nil (Advice by factory executives)

Chemicals and Other Expenditure before Operation= None

Total Pre-production Expenditure = US$83.33

Total Initial Fixed Investment = US$ **(833.33 +416.67 +333.33 + 2083.33 +333.33 + 83.33) = US$4083**

Operating Cost

Raw Material Cost: The raw material is the effluent that is to be disposed off. Thus, there is no cost of the raw material.

2 Costs of Other Inputs:

Cost of Chemicals = US$750 per year

Water = None

Cost of Electricity = US$300 per year

Plant Supervisor (Skilled) = US$41.67

Plant Operator (Semi-skilled) = US$20.83

Total Labor Cost per Annum = US$ (41.66 ×12 +20.83×12) = US$750

Maintenance Cost: 12.5% of purchase price of machinery and equipment) = US$300

Depreciation: Plant and machinery were depreciated on straight line basis at the rate of 10% of the purchase price = US$208.33

Total Operating Cost/Annum = US$ (750 + 300 + 750+300 + 208.33) = US$2308 (Year 1)

Expenditure in Future Years

Apart from the initial investment of US$4,083.33, no other capital expenditure is assumed over the project life under consideration. The operating cost in the base year (2000 - 2001) is nil. It is subject to alteration with changes in labor cost, operating capacity, electricity usage and rate, etc. Riaz tanneries chromium recycling plant is working at 90% of its plant capacity and the Management does not intend to increase it in near future. So currently the optimal plant capacity being utilized is said to be 90% which allows for desirable levels of efficiency needed to recover chromium. After every three years, it is predicted that the salaries of labor are subject to an increase of 15% and prices of utilities and electricity rate experience an increase in cost by 10% every year. The projected operating costs in future 20 years are shown in Table 3 (App. 2) as later sensitivity analysis demands evaluation over 20 years.

Computation of Benefits

Volume of Effluent Processed per Day (Average) = 6,833 Liter

Volume of Effluent Processed per Annum = 6,833 *300 = 2,049,900kg

Basic Chromium Sulfates (BCS) Used per Day (Average) = 460 kg

Average BCS Discharge/ Recycled per Liter Float = 7.53g

Average BCS Discharge of Float / Day = 7.53 * 6,833 = 51,452 g or 51.5 kg/Day

Price of BCS/Kg = US$1.08333

Revenue Return per Annum (Full Price) = US$i.08333 * 51.5 Kg/Day * 300 days = US$16,737

Annual Cash flow in Year 1 (Full Price) = Annual Revenue – Operating Cost = US$ (16,737 – 2,308 = US$14,429

Revenue Return per Annum (Half Price) = US$ 1.08333 * 51.5 Kg/Day * 300 days) /2= US$8,369

Annual Cash flow in Year 1 = Annual Revenue – Operating Cost =

US$ 8,369– 2,308 = US$6,061

Total Expenditure and Total Returns Discounted to the Base Year

Present Value of Expenditure:

Expenditure: Initial Fixed Investment +Operating Cost

Initial Fixed Investment = US$4083.33

The present value of the operating costs in future years were calculated by multiplying with corresponding discount factors as shown in Table 4 (App. 2)

Present Value of Operating Cost = US$17,977.70

Present Value of Cash Outlays (Cost) = US$ (4083.33+17,977.70) = US$22,061

Present Value of Revenue Returns:

Returns = Savings + Scrap Value

The revenue returns from chromium recycling are in the form of constant periodic cash flows of US$16,737.50. The total receipts after discounting at 10% can be calculated by applying Annuity Formula. Thus, Present Value of US$ 1 received constantly per annum for 10 years at 10 % discount rate = US$ 6.14457 (From Annuity Tables).Present Value of US$16,737.50 received constantly per annum for 10 years at 10 % discount rate = US$16,737.50 × 6.14457 = US$102,845

Present Value of Returns = US$102,845

Present Value of Scrap = US$80

Present Value of Cash Flows (Benefits) = US$ (102,845 + 80) = US$102,925

Benefit / Cost (B/C) Ratio

$$\text{B/C Ratio} = \frac{\text{Present Value of Benefits}}{\text{Present Value of Costs}} = \frac{102,925}{22,061} = 4.67$$

NPV= PV of Costs – PV of Benefits = US (-22,061+ 102,925) = US$80,864

Costing by the Application of Payback Period Method

$$\text{Payback Period} = \frac{\text{Total Investment}}{\text{Savings in year1}} = \frac{4083}{14,429} = 0.28\text{ Years} = 100\text{ Days}$$

This is the calculation of PBP if the price of the recycled chrome is considered at par with fresh basic chromium sulfate powder purchased from the market. As the lack of quality finally manifests into the finished product, another scenario develops by allocating less value to the recovered chromium. If we take price of recycled chromium as half that of fresh, it will present the following picture:

$$\text{Payback Period} = \frac{\text{Total Investment}}{\text{Annual Returns}} = \frac{4,083}{6,061} = 0.67\text{ Years} = 241\text{ days}$$

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Appendix 2

Table 1: Total operating cost in future years (US$)

Years	Calculations Operating Cost = Cost of (Labor +Utilities & Chemicals + Maintenance & Depreciation)	Operating Cost
2001-2002	0	0
2002-2003	750 + 1,050+508.33	2308.33
2003-2004	750 + 1,155+508.33	2413.33
2004-2005	750+1,270.50+508.33	2,528.83
2005-2006	862.50+1,397.55+508.33	2,768.38
2006-2007	862.50+1,537.30+508.33	2,908.13
2007-2008	862.50+1,690.03+508.33	3,053.53
2008-2009	991.88+1860.13+508.33	3,360.35
2009-2010	991.88+2046.15+508.33	3,546.36
2010-2011	991.88+2,267.41+508.33	3750.96
2011-2012	1,140.65+2,475.83+508.33	4,124.81
2012-2013	1,140.65+2,723.41+508.33	4,372.40
2013-2014	1,140.65+2995.76+508.33	4644.75
2014-2015	1,311.75+3295.33`+508.33	5115.41
2015-2016	1,311.75+3624.86+508.33	5,444,94
2016-2017	1311.75+3,987.36+508.33	5807.44
2017-2018	1,508.51+4,386.10+508.33	6,402.94
2018-2019	1,508.51+4,824.71+508.33	6,841.55
2019-2020	1,508.51+5,307.18+508.33	7,324.02
2020-2021	1,734.78+5,837.88+508.33	8,080.99
2021-2022	1,734.78+6,421.66+508.33	8,664.77

Table 2: Total operating costs discounted at 10% to the base year (US$)

Years	Calculations	Operating Cost
2001-2002	0	0
2002-2003	2,308.33*0.909091	2,098.48
2003-2004	2,413.33*0.826446	1,994.48
2004-2005	2528.83*0.751315	1,899.94
2005-2006	2,768.38*0.683013	1,890.83
2006-2007	2,908.13*0.620921	1,805.71
2007-2008	3,053.53*0.564474	1,723.63
2008-2009	3,360.35*0.513158	1,724.39
2009-2010	3,546.36*0.466507	1,654.40
2010-2011	3750.96*0.424098	1,590.77
2011-2012	4,124.81*0.385543	1.590.29
Present Value of Total Operating Cost		17,973

Table 3: Different scenarios of reported efficiency – US $

Efficiency	40%	50%	60%	70%	80%	90%
Revenue (p.a.)	6,695	8,369	10,043	11,716	13,390	15,063
Op. Cost Year 1	2,098	2,098	2098	2098	2098	2098
Savings Year 1	4,597	6,271	7,945	9,618	11,292	12,970
Initial Investment	4,083	4,083	4,083	4,083	4,083	4,083
Payback(Years)	0.88	0.65	0.51	0.42	0.36	0.31