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Appendices

1. Cost analysis of the proposed process

Assumptions:

- Overhead cost, labor cost, manpower and DI water costs are considered as 10% of total cost.
- Assume utilization of maximum power of instruments and cost per unit Rs.12/- in Varanasi.
- Cost is mentioned in INR

Value of recovered metals as per market price (Varanasi): (29th Aug 2022; Source: google)

S. No.	Metal	Quantity	Price for unit quantity (INR)		Total (INR)
1.	Copper	91 kg	700/kg	700*91	63700
2.	Gold	50 g	5300/g	5300*50	265000
3.	Nickel	0.6 kg	1720/kg	1720*0.6	1032
4.	Silver	30 g	54/g	54*30	1620
5.	Zinc	1 kg	250/kg	250*1	250
Total price					331602

Cost of proposed process for valuable metals:

S. No.	Unit process	Input (per day)	Output (per day)	Cost (INR)
1.	Collection of waste PCBS	250 kg	250 kg	**75000**
2.	Delamination	WPCB Dimethylacetamide (DMA) Electricity	100 kg metallic -fraction Regenerated DMA	**11872**
3.	Stage-1 Leaching	Metallic fraction PCBs 3M nitric acid Electricity	Base metal Leach-Solution Gold rich residue	**8480**

4.	Solvent extraction of copper	2M Ammonia Kerosene ACORGA M 5640 Electricity	Copper rich-organic solution Nickel rich - raffinate	**11405**
5.	Stripping of copper	Copper rich organic solution 4M Sulphuric acid Electricity	Copper sulphate -solution Recycled organic - solution	**15480**
6.	Electrowinning	Copper sulphate solution Electricity	Copper metal	**900**
7.	Solvent extraction of nickel	Nickel rich raffinate from -copper SX 2M Ammonia Kerosene ACORGA M 5640	Nickel rich organic - solution Raffinate with - other minor - elements	**6040**
8.	stripping	Nickel rich organic - solution 1M nitric acid	Nickel solution	**6500**
9.	Electrowinning of nickel	Pure nickel solution	Nickel metal	**900**
10.	Stage 2 Leaching	Stage 1 Leach residue Sodium bromide Sulphuric acid electricity	Gold rich leach -liquor	**35240**
11.	Solvent extraction of gold	Gold rich leach liquor Toluene Tertiary amide Electricity	Gold rich organic - solution Raffinate Electricity	**15980**
12.	Stripping	Gold rich organic solution 1M sodium hydroxide electricity	Gold solution	**15480**
13.	Silver cementation	Raffinate of gold SX Copper powder electricity	Silver metal	**9480**
14.	Cementation of other metals	Ni Raffinate with other - minor elements Zn dust Electricity	Pure zinc solution	**980**
15.	Total cost			**213737**
16.	Overhead cost+ labor cost, + manpower and DI water costs are			**21374**

	considered as 10% of total cost.			
17.	Total cost of production of the valuable metals with the proposed process			***235111***

PROJECTED PROFIT BEFORE TAX: 331602.00-235111.00 = Rs. 96491.00 per day

Detailed explanation:

Collected PCBs: 250 kg

Cost of waste PCBs = Rs. 75000/-

Step 1: Delamination for the separation of metallic and non-metallic fraction:

N, N-Dimethylacetamide (DMA) (300g PCBs/500 mL) cost: Rs. 170/- per liter

For 250 kg, 416 liters required

Total DMA cost 170*416= Rs. 70720/-

Electricity charges for delamination:

1 unit (kW) charges: Rs. 12/- (Assumption)

Power: 20 kW [assumption based on (Carlos Eyzaguirre et al., 2015)[1]], Time: 15 h;

Electricity units: 300 units

Electricity charges: 300*12=Rs. 3600/-

100 electricity units for recycling of DMA (20 kW*5 h)

1 unit (kW) charges: Rs. 12/-

Approximate electricity charges for recycling (100*12): Rs. 1200/-

Product: 100 kg delaminated metallic fraction

Recycled DMA (if 10% losses observed in larger quantity) 70720*(90/100) = Rs. 63648/-

Total cost for delamination: Rs.70720+3600+1200-63648=Rs. 11872/-

Stage-1 Leaching

S/L ratio for leaching; 1g:20 mL

Leaching setup power: 20 kW, 2 h leaching

Nitric acid (3M) cost: Rs. 4/- [conc. HNO_3 cost: Rs. 24/- per 1000 mL in bulk]

Nitric acid cost = 4*2000= Rs. 8000/-

Electricity charges (40*12) = Rs. 480/-

Total cost for the leaching of 100 kg metallic fraction: Rs. 8480/-

Product 5000 L

Solvent Extraction of cu

2M Ammonia for pH modification:

Product: 5000 L [after addition of 2M ammonia ~5100 L)

For 1L ammonia = Rs. 46/-

For 100 L: Rs. 4600/-

Assume 20 cycles for solvent extraction

Kerosene (70%) + ACORGA M5640 (30%) for 1 cycle (250 L)

Kerosene (175 L) + ACORGA M5640 (75 L)

175*40 + 75*750 = Rs. 63250/-

Reuse for every 20 cycles

Electricity charges for 20 cycle= Rs. 480/- [0.6 kW, 20 min, Rs.12/-per unit]

If 10% losses observed after regeneration, cost of kerosene + acorga = Rs. 56925/-

Total cost for extraction: Rs. 11405/-

Stripping

Sulphuric acid (4M): Rs. 3/- [14/- Conc. /L]

3*5000= Rs. 15000/-

Electricity charges = Rs. 480/-

Total cost for stripping: Rs. 15480/-

Electrowinning

Electrowinning charges: 0.75 kWh/kg cu [Hannula p m et al., 2019]

0.75*100*12= Rs. 900/-

Total cost for electrowinning: Rs. 900/-

Solvent extraction and stripping for Ni

2M Ammonia [similar to cu SX]: Rs. 4600/-

Electricity charges [0.6 watt, 1 hour, 12/-per unit]: Rs. 1440/-

Oxime and kerosene cost: [use same reagents used for solvent extraction of copper]

Nitric acid (1M) for stripping: Rs. 1.3 [20/- conc. nitric acid/L]

5000*1.3 = Rs. 6500/-

Total cost for nickel recovery: Rs. 12540/-

Electrowinning

Electrowinning charges: Rs. 900/- (Assumption)

Stage 2 leaching (gold leaching)

3M Sulphuric acid: Rs. 2.5*2000 = Rs. 5000/-

3M Sodium Bromide: Rs. 15*2000 = Rs. 30000/- [150/kg]

Electricity charges: [similar to stage 1 leaching but 1 h leaching] =Rs. 240/-

Total cost for stage -2 leaching: Rs. 35240/-

Product 5000 L

Solvent extraction of gold

Toluene: 50/- per liter

Acyl chloride 0.1 M Rs. 12/- for the synthesis of amide

Recycled and reuse for every 20 cycles

Toluene cost: 50*250= Rs. 12500/-

Acyl chloride cost: 12*250= Rs. 3000/-

Electricity charges: Rs. 480/-

Stripping

Sodium hydroxide 1M (40g/L) = Rs. 3/-

For 5000 Liters: Rs. 15000/-

Electricity charges: Rs. 480/-

Total cost for solvent extraction and stripping: Rs. 31460/-

Silver cementation

3 g copper for 1liter

5000 litres: 1.5 kg *600 = Rs. 9000/-

Electricity charges: Rs. 480/-

Total cost for silver cementation: Rs. 9480/-

Other metals cementation to separate zinc:

Electricity charges: Rs. 480/-

Zinc dust for 1L = 0.4g [kg 250/-]

5000 liters = 2000 g; cost Rs. 500/-

Total cost for zinc production: Rs. 980/-

Total cost [addition of highlighted part]: Rs. 213737/-

Labour+ instrument cost+ man power+ DI water = 10% of total cost (assumption) = Rs. 21374/-

Total cost of production of valuable metals: Rs. 235111.00

Quantity of recycled metals produced: [91 kg copper, 50 g gold, 0.6 Kg nickel, 30 g silver, 1 kg zinc]

Value of recovered metals as per market price (Varanasi): (29th Aug 2022; Source: google)

91 kg copper (91*700) = Rs. 63700/-

50 g gold (50*5300) = Rs. 265000/-

0.6 kg nickel (0.6*1720) = Rs. 1032/-

30 g silver (30*54) = Rs. 1620/-

1 kg zinc (1*250) = Rs. 250/-

Total value of recycled metals produced: Rs. 331602.00

PROJECTED PROFIT BEFORE TAX: 331602.00-235111.00 = Rs. 96491.00 per day

List of Publications

International Journal Publications (indexed in Web of Science/ SCI/Scopus)

S. No.	Title	Journal & Impact factor
1.	Challenges and opportunities in the recovery of gold from electronic waste. ***RSC Adv.*, 2020, 10, 4300-4309.**	***RSC Advances (4.036)***
2.	Recycling copper and gold from e-waste by a two stage leaching and solvent extraction process. ***Sep. Purif. Technol.*, 2021, 263, 118400.**	***Separation and Purification Technology (9.136)***
3.	Optimization of process parameters for the selective leaching of copper, nickel and isolation of gold from obsolete mobile phone PCBs. ***Clean. Eng. Technol.*, 2021, 4, 100180.**	***Cleaner engineering and technology***
4.	Selective recovery of nickel from obsolete mobile phone PCBs ***Hydrometallurgy, 2022, 210, 105843.***	***Hydrometallurgy (4.156)***

Conference proceedings

S. No.	Title	Proceedings
1.	Optimization of leaching of copper to enhance the recovery of gold from liberated metallic layers of WPCBs. ***Mat. Pr.*, 2021, 46(3) 1515-1518.** ***Metwaste-2020, Varanasi, February 22-23, 2020.***	***Materials Today: Proceedings (1.24)***
2.	Recycling recovery of gold by leaching and solvent extrction from chemically pre-treated obsolete mobile phone PCBs ***ICNFM-2021, New Delhi, September 3-4, 2021.***	***International conference on Non-Ferrous Metals***