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Design of 3,000,000tons/yr A-20 dry cell plant

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ABSTRACT

A design for the production 3,000,000ton/yr A-20 dry cell plant to help in alleviating the problem of power supply to portable electronic devices and offer employment opportunity to teeming unemployed youth in Nigeria was carried out. This is done to bringing the much needed revenue to local economies, providing jobs and improving the lives of people. Since job creation especially for youth, reducing poverty are criteria for macroeconomics success.
A medium scale plant for the production of A-20 dry cell using paper lined system of 4wt% zinc and 8wt% NH_4Cl was designed. The material and energy balance of the production were given. Results obtained revealed that the net profit (₦9.471 x 10^6) when compared with the total production cost (₦6.386 x 10^7) shows that the project is economically viable.

INTRODUCTION

Dry cell, also known as Leclanche cell or a zinc-carbon battery is a form of primary electrochemical cell that supplies electrical energy at small currents by converting chemical energy into electricity. This battery is not rechargeable; therefore, it is discarded once it has produced all its electrical energy because the chemicals cannot be reconstituted into their original form once the energy has been converted. It is compact and reliable; hence it is commonly used to power portable electronic devices such as radios and flashlights, toys, hearing aids, smoke detectors etc.

Like all electrochemical cells, the dry cell gets its electrical energy from an internal chemical reaction which takes the form of two half-cell reactions. The electrolyte in the cell consists of ammonium chloride, manganese (IV) oxide, finely granulated carbon and inert filler which is usually starch. The ammonia from the ammonium ions forms the complex ion $Zn(NH_3)_4^{2+}$ with the Zn^{2+} preventing build up of Zn ions which would result in reduction of the potential of the cell.

In standard electrochemical cell notation the dry cell looks like:
(-) $Zn(s)| ZnCl_2\ (aq), NH_4Cl(aq)| MnO(OH)(s)| MnO_2(s)|$ graphite (+)
With a cell potential of approximately 1.5V and the following half-cell reactions

Oxidation (At the anode (-)):
$Zn(s) \rightarrow Zn^{2+}(aq) + 2e^-$

Followed by
$Zn^{2+}(aq) + 2NH_3(g) \rightarrow [Zn(NH_3)_2]^{2+}\ (aq)$

Reduction (At the cathode (+)):
$MnO_2(s) + H_2O(l) + e^- \rightarrow MnO(OH)(s) + OH^-(aq)$ (Anderson, 2004; Linford, 1990; Urells, 1995; Mantel, 1950).

Material balance

The compositions of dry cell electrolyte are 15% $ZnCl_2$ and 27%NH_4Cl in water . At these concentrations most of the zinc in solution exists as complex ion $ZnCl^{-4}$. Therefore, the reaction below is the simple representation of the actual natural process that occurs in a dry cell.

$$Zn_{(s)} + 2MnO_{(s)} + 2NH_4Cl_{(aq)} \rightarrow Zn(NH)_3Cl_2(aq) + 2MnOOH_{(aq)}$$

$$mass\ accumulated = mass\ input - mass\ output + mass\ generated - mass\ consumed$$

Using the steady state equation without reaction, where the values of the variables within the system do not change with time hence accumulation is zero by definition.

$$mass\ input = mass\ output$$

But in the furnace, there is 3% accumulation of zinc therefore the material balance around the furnace is given as

$$mass\ accumulated = mass\ input - mass\ output$$

The material balances around the furnace, extruder, electrolyte mixer, electrolytic cell, cathode mixer, starch mixer, kneader wax unit are given in tables 1.1 – 1.8

Table 1.1
FURNACE
Assumption : 3% accumulation of zinc

	Input			Accumulation			Output		
Component	Kg	kg/year	wt%	Kg	kg/year	wt%	Kg	kg/year	wt%
Zn	100	125715241.2	100	3	3771457.23	100	97	121943783.9	100
NH_4Cl	0	0	0	0	0	0	0	0	0
MnO_2	0	0	0	0	0	0	0	0	0
$ZnCl_2$	0	0	0	0	0	0	0	0	0
H_2O	0	0	0	0	0	0	0	0	0
Carbon	0	0	0	0	0	0	0	0	0
Starch	0	0	0	0	0	0	0	0	0
Wax	0	0	0	0	0	0	0	0	0
$MnSO_4$	0	0	0	0	0	0	0	0	0
Total	100	125715241.2	100	3	3771457.23	100	97	121943783.9	100

Table 1.2 EXTRUDER

	Input			**Output**		
Component	Kg	kg/year	wt%	kg	kg/year	wt%
Zn	97	121943783.9	100	97	121943783.9	100
NH_4Cl	0	0	0	0	0	0
MnO_2	0	0	0	0	0	0
$ZnCl_2$	0	0	0	0	0	0
H_2O	0	0	0	0	0	0
Carbon	0	0	0	0	0	0
Starch	0	0	0	0	0	0
Wax	0	0	0	0	0	0
$MnSO_4$	0	0	0	0	0	0
Total	97	121943783.9	100	97	121943783.9	100

Table.1.3 ELECTROLYTE MIXER

	Input			Addition			Output		
Component	Kg	kg/year	wt%	kg	kg/year	wt%	kg	kg/year	wt%
Zn	97	121943783.9	100	0	0	0	97	121943783.9	17.3913
NH_4Cl	0	0	0	194	243887568	42.10526	194	243887567.8	
MnO_2	0	0	0	0	0	0	0	0	0
$ZnCl_2$	0	0	0	24.25	30485946	5.263158	24.25	30485945.98	347826
H_2O	0	0	0	242.5	304859460	52.63158	242.5	304859459.8	3.47826
Carbon	0	0	0	0	0	0	0	0	0
Starch	0	0	0	0	0	0	0	0	0
Wax	0	0	0	0	0	0	0	0	0
$MnSO_4$	0	0	0	0	0	0	0	0	0
Total	97	121943783.9	100	460.75	579232974	100	557.75	701176757.5	100

Table1.4 ELECTROLYTE CELL

	Input			Addition			Output		
Component	Kg	kg/year	wt%	kg	kg/year	wt%	Kg	kg/year	wt%
Zn	97	121943783.9	17.3913	0	0	0	97	121943783.9	10.81081
NH_4Cl	194	243887567.8	34.78261	0	0	0	194	243887567.8	21.62162
MnO_2	0	0	0	0	0	0	0	0	0
$ZnCl_2$	24.25	30485945.98	4.347826	0	0	0	24.25	30485945.98	2.702703
H_2O	242.5	304859459.8	43.47826	0	0	0	242.5	304859459.8	27.02703
Carbon	0	0	0	0	0	0	0	0	0
Starch	0	0	0	0	0	0	0	0	0
Wax	0	0	0	0	0	0	0	0	0
$MnSO_4$	0	0	0	339.5	426803243.7	100	339.5	426803243.7	37.83784
Total	557.75	701176757.5	100	339.5	426803243.7	100	897.25	1127980001	100

Table.1.5 CATHODE MIXER

	Input			Addition			Output		
Component	Kg	kg/year	wt%	Kg	kg/year	wt%	Kg	kg/year	wt%
Zn	97	121943783.9	10.81081	0	0	0	97	121943783.9	6.4516129
NH_4Cl	194	243887567.8	21.62162	0	0	0	194	243887567.8	12.903226
MnO_2	0	0	0	339.5	426803243.7	56	339.5	426803243.7	22.580645
$ZnCl_2$	24.25	30485945.98	2.702703	0	0	0	24.25	30485945.98	1.6129032
H_2O	242.5	304859459.8	27.02703	0	0	0	242.5	304859459.8	16.129032
Carbon	0	0	0	266.75	335345405.8	44	266.75	335345405.8	17.741935
Starch	0	0	0	0	0	0	0	0	0
Wax	0	0	0	0	0	0	0	0	0
$MnSO_4$	339.5	426803243.7	37.83784	0	0	0	339.5	426803243.7	22.580652
Total	897.25	1127980001	100	606.25	762148649	100	1503.5	1890128651	100

Table 1.6 ELECTROLYTE STARCH MIXER

	Input			Addition			Output		
Component	kg	kg/year	wt%	kg	kg/year	wt%	kg	kg/year	wt%
Zn	97	121943783.9	6.451612903	0	0	0	97	121943783.9	4.081633
NH_4Cl	194	243887567.8	12.90322581	0	0	0	194	243887567.8	8.163265
MnO_2	339.5	426803243.7	22.58064516	0	0	0	339.5	426803243.7	14.28571
$ZnCl_2$	24.25	30485945.98	1.612903226	0	0	0	24.25	30485945.98	1.020408
H_2O	242.5	304859459.8	16.12903226	0	0	0	242.5	304859459.8	10.20408
Carbon	266.75	335345405.8	17.74193548	0	0	0	266.75	335345405.8	11.22449
Starch	0	0	0	873	1097494055	100	873	1097494055	36.73469
Wax	0	0	0	0	0	0	0	0	0
$MnSO_4$	339.5	426803243.7	22.5806516	0	0	0	339.5	426803243.7	14.28571
Total	1503.5	1890128651	100	873	1097494055	100	2376.5	2987622706	100

Table1.7
KNEADER

	Input			Accumulation			Output		
Component	kg	kg/year	wt%	Kg	kg/year	wt%	Kg	kg/year	wt%
Zn	97	1219437839	4.081633	0.97	1219437.84	4.081633	96.03	120724346.1	4.081633
NH_4Cl	194	2438875678	8.163265	1.94	2438875.68	8.163265	192.06	241448692.2	8.163265
MnO_2	339.5	4268032437	14.28571	3.395	4268032.44	14.28571	336.105	422535211.3	14.28571
$ZnCl_2$	24.25	30485945.98	1.020408	0.2425	304859.46	1.020408	24.0075	30181086.52	1.020408
H_2O	242.5	3048594598	10.20408	2.425	3048594.6	10.20408	240.075	301810865.2	10.20408
Carbon	266.75	3353454058	11.22449	2.6675	3353454.06	11.22449	264.0825	331991951.7	11.22449
Starch	873	1097494055	36.73469	8.73	10974940.6	36.73469	864.27	1086519115	36.73469
Wax	0	0	0	0	0	0	0	0	0
$MnSO_4$	339.5	4268032437	14.28571	3.395	4268032.44	14.28571	336.105	422535211.3	14.28571
Total	2376.5	2987622706	100	23.765	29876227.12	100	2352.735	2957746479	100

Table 1.8
WAX UNIT

	Input			Addition			Output		
Component	kg	kg/year	wt%	Kg	kg/year	wt%	Kg	kg/year	wt%
Zn	96.03	1207243461	4.081633	0	0	0	96.03	1207243461	4.024145
NH_4Cl	192.06	2414486922	8.163265	0	0	0	192.06	2414486922	8.04829
MnO_2	336.105	4225352113	14.28571	0	0	0	336.105	4225352113	14.08451
$ZnCl_2$	24.0075	30181086.52	1.020408	0	0	0	24.0075	30181086.52	1.006036
H_2O	240.075	3018108652	10.20408	0	0	0	240.075	3018108652	10.06036
Carbon	264.0825	331991951.7	11.22449	0	0	0	264.0825	331991951.7	11.0664
Starch	864.27	1086519115	36.73469	0	0	0	864.27	1086519115	36.2173
Wax	0	0	0	33.6105	42253521.1	100	33.6105	42253521.1	1.408451
$MnSO_4$	336.105	4225352113	14.28571	0	0	0	336.105	4225352113	14.08451
Total	2352.735	2957746479	100	33.6105	42253521.1	100	2386.3455	3000000000	100

Conversion: 1 ton/year 1000 kg/year
Production rate : 3000000 ton/year = 3000000000 kg/year
A-20 dry cell obtained from the basis : 2386.3455

Energy balance

$energy\ accumulated = energy\ input - energy\ output + energy\ generated - energy\ consumed$

$\Delta T = T - Tr$; Where T and Tr are operating temperature and room temperature respectively

T =302K, Tr = 298K ΔT = 4K

$\Delta H = nCp\Delta T$

Using the general energy equation without reaction, where the values of the variables within the system do not change with time hence accumulation is zero by definition.

$energy\ input = energy\ output$

The energy balances around the furnace, extruder, electrolyte mixer, electrolytic cell, cathode mixer, starch mixer, kneader, and wax unit are given in tables 2.2 –.2.9.

Table 2.1 Thermodynamic properties

Component	Molecular weight kg/kmol	Heat of formation kJ/kmol	Specific heat capacities kJ/kmol.K
Zn	65	0	20.786
NH_4Cl	53	0	215.9
MnO_2	88	0	549.5
$ZnCl_2$	135	-9.786×10^5	60.48
H_2O	18	-1.039×10^5	97.207
Carbon	12	0	-4.461×10^{11}
Starch	810	-9.456×10^5	44.384
Wax	850	-2.963×10^5	-39.722
$MnSO_4$	15	-6.018×10^5	41.899

Table 2.2 FURNACE

	No of moles : kmol/yr		Enthalpy kJ/year	
Component	Input	Output	Input	Output
Zn	125715241.2	121943783.9	1.045×10^{10}	1.014×10^{10}
NH_4Cl	0	0	0	0
MnO_2	0	0	0	0
$ZnCl_2$	0	0	0	0
H_2O	0	0	0	0
Carbon	0	0	0	0
Starch	0	0	0	0
Wax	0	0	0	0
$MnSO_4$	0	0	0	0

Table 2.3 EXTRUDER

	No of moles : kmol/yr		Enthalpy kJ/year	
Component	Input	Output	Input	Output
Zn	125715241.2	121943783.9	1.045×10^{10}	1.014×10^{10}
NH_4Cl	0	0	0	0
MnO_2	0	0	0	0
$ZnCl_2$	0	0	0	0
H_2O	0	0	0	0
Carbon	0	0	0	0
Starch	0	0	0	0
Wax	0	0	0	0
$MnSO_4$	0	0	0	0
Total				

Table 2.4 ELECTROLYTE MIXER

	No of moles : kmol/yr		Enthalpy kJ/year	
Component	Input	Output	Input	Output
Zn	125715241.2	121943783.9	1.045×10^{10}	1.014×10^{10}
NH_4Cl	0	243887567.8	0	2.106×10^{11}
MnO_2	0	0	0	0
$ZnCl_2$	0	30485945.98	0	7.375×10^{9}
H_2O	0	304859459.8	0	1.185×10^{11}
Carbon	0	0	0	0
Starch	0	0	0	0
Wax	0	0	0	0
$MnSO_4$	0	0	0	0
Total				3.467×10^{11}

Table 2.5 ELECTROLYTE CELL

	No of moles : kmol/yr		Enthalpy kJ/year	
Component	Input	Output	Input	Output
Zn	121943783.9	121943783.9	1.014×10^{10}	1.014×10^{10}
NH_4Cl	243887567.8	243887567.8	2.106×10^{11}	2.106×10^{11}
MnO_2	0	0	0	0
$ZnCl_2$	30485945.98	30485945.98	7.375×10^{9}	7.375×10^{9}
H_2O	304859459.8	304859459.8	1.185×10^{11}	1.185×10^{11}
Carbon	0	0	0	0
Starch	0	0	0	0
Wax	0	0	0	0
$MnSO_4$	0	426803243.7	0	7.153×10^{10}
Total			3.467×10^{11}	4.182×10^{11}

Table 2.6 CATHODE MIXER

	No of moles : kmol/yr		Enthalpy kJ/year	
Component	Input	Output	Input	Output
Zn	121943783.9	121943783.9	1.014×10^{10}	1.014×10^{10}
NH_4Cl	243887567.8	243887567.8	2.106×10^{11}	2.106×10^{11}
MnO_2	0	426803243.7	0	9.382×10^{11}
$ZnCl_2$	30485945.98	30485945.98	7.375×10^{9}	7.375×10^{9}
H_2O	304859459.8	304859459.8	1.185×10^{11}	1.185×10^{11}
Carbon	0	335345405.8	0	-5.984×10^{20}
Starch	0	0	0	0
Wax	0	0	0	0
$MnSO_4$	426803243.7	426803243.7	7.153×10^{10}	7.153×10^{10}
Total			4.182×10^{11}	-5.984×10^{20}

Table 2.7 ELECTROLYTE STARCH MIXER

Component	No of moles : kmol/yr Input	Output	Enthalpy kJ/year Input	Output
Zn	121943783.9	121943783.9	1.014×10^{10}	1.014×10^{10}
NH_4Cl	243887567.8	243887567.8	2.106×10^{11}	2.106×10^{11}
MnO_2	426803243.7	426803243.7	9.382×10^{11}	9.382×10^{11}
$ZnCl_2$	30485945.98	30485945.98	7.375×10^{9}	7.375×10^{9}
H_2O	304859459.8	304859459.8	1.185×10^{11}	1.185×10^{11}
Carbon	335345405.8	335345405.8	-5.984×10^{20}	-5.984×10^{20}
Starch	0	1097494056	0	1.948×10^{11}
Wax	0	0	0	0
$MnSO_4$	426803243.7	426803243.7	7.153×10^{10}	7.153×10^{10}
Total			-5.984×10^{20}	-5.984×10^{20}

Table 2.8 KNEADER

Component	No of moles : kmol/yr Input	Output	Enthalpy kJ/year Input	Output
Zn	121943783.9	120724346.1	1.014×10^{10}	1.004×10^{10}
NH_4Cl	243887567.8	241448692.2	2.106×10^{11}	2.085×10^{11}
MnO_2	426803243.7	422535211.3	9.382×10^{11}	9.288×10^{11}
$ZnCl_2$	30485945.98	30181086.52	7.375×10^{9}	7.301×10^{9}
H_2O	304859459.8	301810865.2	1.185×10^{11}	1.174×10^{11}
Carbon	335345405.8	331991951.7	-5.984×10^{20}	-5.924×10^{20}
Starch	1097494056	1086519115	1.948×10^{11}	1.929×10^{11}
Wax	0	0	0	0
$MnSO_4$	426803243.7	422535211.3	7.153×10^{10}	7.081×10^{10}
Total			-5.984×10^{20}	-5.924×10^{20}

Table 2.9 WAX UNIT

Component	No of moles : kmol/yr Input	Output	Enthalpy kJ/year Input	Output
Zn	120724346.1	120724346.1	1.004×10^{10}	1.004×10^{10}
NH_4Cl	241448692.2	241448692.2	2.085×10^{11}	2.085×10^{11}
MnO_2	422535211.3	422535211.3	9.288×10^{11}	9.288×10^{11}
$ZnCl_2$	30181086.52	30181086.52	7.301×10^{9}	7.301×10^{9}
H_2O	301810865.2	301810865.2	1.174×10^{11}	1.174×10^{11}
Carbon	331991951.7	331991951.7	-5.924×10^{20}	-5.924×10^{20}
Starch	1086519115	1086519115	1.929×10^{11}	1.929×10^{11}
Wax	0	42253521.3	0	-6.714×10^{9}
$MnSO_4$	422535211.3	422535211.3	7.081×10^{10}	7.081×10^{10}
Total			-5.924×10^{20}	-5.924×10^{20}

ECONOMIC EVALUATION

Table 3.1: EQUIPMENT COST ANALYSIS

Equipment unit	Marshall and Smith equation	Area m^2	Diameter M	Height m	Material for construction	Unit cost ₦
Furnace	$Pc_{furnace} = \frac{ms}{280}(101.3A^{0.65}. Fc)$	9.9	--	--	Stainless steel	2.596×10^5
Extruder	$Pc = \frac{ms}{280}(101.9D^{1.066} H^{0.802}. Fc)$	--	3.913	4.304	Stainless steel	8.123×10^5
Electrolyte mixer	Same as above	--	3.206	6.412	Carbon steel	9.042×10^5
Electrolyte cell	Same as above	--	5.537	5.814	Carbon steel	1.497×10^6
Cathode mixer	Same as above	--	4.699	5.873	Carbon steel	1.267×10^6
Starch mixer	Same as above	--	4.809	4.857	Carbon steel	1.115×10^6
Kneader	Same as above	--	4.892	4.647	Carbon steel	1.096×10^6
Total	6.95×10^6					

Assuming the initial fixed investment for the plant is the total purchased cost equipment; the **initial fixed capital investment** (FCI) is equal to ₦6.95 x 10^6.

Ms = numerical value for marshall and smith index (1100)

Table 3.2: Projected income and expenses statement for the year 2012 to 2015

DESCRIPTION	YEARS			
	2012.00	**2013.00**	**2014.00**	**2015.00**
Tones/yr	30000000.00	3428571.43	3857142.86	4285714.29
Capacity (%)	70.00	80.00	90.00	100.00
REVENUE		Amount in ₦		
Net sales	36843.64	42107.02	47470.39	52633.77
EXPENDITURE				
Raw material	137388.17	157015.05	176641.93	196268.81
Factory labour	44861.44	51270.22	5769.00	64087.77
Depreciation	20624.04	23570.33	26516.62	29462.91
Overhead	75797.85	86626.11	97454.38	108282.64
TOTAL	278671.50	318481.71	358291.93	398102.14
PROFIT				
Before tax	75797.85	86626.11	97454.38	108282.64
Tax	11369.68	12993.92	14618.16	16242.40
Net profit	64428.17	73632.20	82826.22	92040.25

CONCLUSION

The total production cost ₦ 6.386×10^7 and a net profit of ₦9.471×10^6 have revealed that the project is economically viable with a payback period of 3 years approximately

Appendix

Assumptions

1. Composition of dry cell electrolyte are 15% $ZnCl_2$ and 27% NH_4Cl in Water.
2. Thickness of the cylinder to be 0.60mm.
3. 45% cathode is electrolyte
4. 5% of Weight of Cathode is acetylene carbon
5. 15% by Weight of electrolyte is $ZnCl_2 = 0.15Y$
6. 85% of the electrolyte Y is poured into the cathode.
7. 27% by weight of electrolyte is ammonium chloride
8. 58% by weight of electrolyte is distilled water
9. 15% by weight of electrolyte is mixed with starch
10. Steel sheet of 0.05cm thickness
11. Density of stainless steel = $7.86 g/cm^3$
12. Sleet size is 6.15cm by 3.48cm
13. 15% by Weight of the metal jacket is the metal top
14. Production Rate per Day = Production Rate.

Zinc Anode

The cylindrical shape size of A-20 dry cell has the following data:

Density of zinc(ρzinc) = $7.14 g/cm^3$

Height of the cylinder, $H_{cylinder} := 6.15cm$

Inner diameter of the cylinder, $D_i = 3.42cm$

Assuming the thickness of the cylinder to be =0.6mm

The outer diameter of the cylinder, $D_0 = D_i + \text{thickness}$

$D_0 = 0.035m$

$$V_{cylinder} = \pi \left(\frac{D0^2}{4} \frac{Di^2}{4} \right) H_{cylinder}$$

$V_{cylinder} = 2cm^3$

Mass of the zinc anode, $M_{zinc} = V_{cylinder} \cdot \rho_{zinc}$

$M_{zinc} = 14.278$ g/cell

Manganese (IV) Oxide

1 mole of zinc reacts with 2 moles of MnO_2

65g/gmole of zinc reacts with 174g/gmole of MnO_2

Therefore, 14.25g of zinc will react with

$$\frac{14.28.g.174.\frac{g}{gmol}}{65.\frac{g}{gmol}} = 38.226\frac{g}{cell}$$

Cathode Components
The cathode mixture of the dry cell is presented in the table below.

Components	Weight%
MnO2	50
Electrolyte	45
Carbon	5
Total	100

50 w% of cathode MnO_2 = 38.23g
X = the total weight of the cathode (g)
Then, 0.5X = 38.23g

$$X = \frac{38.23}{0.5} \qquad = 76.46g$$

Electrolyte
45% of cathode is electrolyte, therefore,
Mass of electrolyte in the cathode = 0.45 x 76.46.g = 34.407 g/cell

Acetylene Carbon
5% weight of cathode is acetylene carbon (carbon)
Therefore, mass of carbon in the cathode = 0.05 x 76.46g = 3.823 g/cell

Electrolyte Components
The electrolyte of the dry cell consists of the components presented in the table below:

Components	Weight%
$ZnCl_2$	15
NH_4Cl	27
H_2O	58
Total	100

Assuming that 85% of the electrolyte Y is poured into the cathode, then 0.85Y= 34.41g

$$\text{Electrolyte} = \frac{34.41\frac{g}{gmol}}{0.85}$$

Y = 40.482 g/cell
Zinc Chloride ($ZnCl_2$)
15% by weight of electrolyte is $ZnCl_2$ = 0.15Y

$$0.15 \times 40.48g = 6.072\frac{g}{cell}$$

$$ZnCl_2 = 6.072\frac{g}{cell}$$

Ammonium Chloride (NH_4Cl)
27% by weight of electrolyte is ammonium chloride
Therefore, mass of NH_4Cl in the electrolyte is
NH_4Cl:= 0.27 Electrolyte

$$NH_4Cl = 10.93\frac{g}{cell}$$

Distilled Water
58% by weight of electrolyte is distilled water

Mass of distilled water per cell is
$H_20 = 0.5.8$ Electrolyte

$H_2O = 23.48 \frac{g}{cell}$

Electrolyte Starch – mix
Assuming 15% by weight of electrolyte is mixed with starch
0.15Y is mixed with starch
Starch = 0.15. Y

Starch = $6.072 \frac{g}{cell}$

Steel Metal Jacket
Using steel sheet of 0.05cm thickness

Density of steel, ρsteel = $7.86 \frac{g}{cm^3}$

Using sheet size of 6.15cm by 3.48cm

The volume of the sheet, V_{sheet} = 6.15cm. 3.48. cm 0.05cm
Vsheet = $1.07cm^3$

Assuming that the metal top is 05% by weight of the metal jacket, then mass of the metal top,

$M_{top} = 0.05.8.41 \frac{g}{cell}$

$M_{top} = 0.421 \frac{g}{cell}$

Production Rate

Production Rate = $\frac{3000000.tonne}{yr}$

Production Rate = $3 \times 10^9 \frac{kg}{yr}$

Assuming 330 working days per year, that is, yr= 330. Day

Production rate / day = $8.214 \times 10^6 \frac{kg}{day}$

Using a basis of 8 hours / day of production time
Production/hour = Production rate/day

$= 3.422 \times 10^5 \frac{kg}{hr}$

Estimation of total capital investment

I. Direct Cost

1. Purchased equipment cost (PEC)	₦ 2.711×10^6
15 -40% of FCI, (39% FCI)	
2. Installation, including insulation and painting	₦ 1.437×10^6
25 – 55% of PEC, (53% PEC)	
3. Instrumentation and controls installed	₦ 9.487×10^5
6 – 30% of PEC, (35% PEC)	
4. Piping installed	₦ 2.033×10^6
10 – 80% of PEC, (75% PEC)	
5. Electrical installed	₦ 9.487×10^5
10 – 40% of PEC, (35% PEC)	
6. Buildings, process and auxiliary	₦ 1.762×10^6
10 – 70% of PEC, (65%PEC)	
7. Service facilities and yard improvements	₦ 1.897×10^6

40 – 100% of PEC, (70%PEC)
8. Land ₦ 1.355 x 10^5
1 – 2% of FCI or 4 – 8% of PEC, (5%PEC)
TOTAL ₦ 1.187 x 10^7
II. Indirect cost
These are expenses which are not directly involved with material and labour of actual installation of complete facility. They are 15 – 30% FCI
1. Engineering and supervision ₦ 2.968 x 10^6
5 – 30% of direct cost, (25%)
2. Construction expense and contractor's fee
30 -60% of direct cost, (55%) ₦6.53 x 10^6
3. Contingency
5-15% of direct cost (13%) ₦1.543 x 10^6
TOTAL ₦1.104 x 10^7
III. Fixed Capital Investment
Fixed CI = Direct Cost + Indirect Cost ₦2.291 x 10^7
IV. Working Capital,
11-20% of fixed capital investment (11%) ₦2.521 x 10^6
V. Total Capital Investment (TCI)
Total Cl = Fixed Cl + Working C ₦2.544 x 10^7

Estimation of Total Product Cost
I. Manufacturing Cost = Direct production + Fixed charges + Plant overhead cost
A. Fixed Charges
10-20% of total product cost
(i) Depreciation
13% of FCI for machinery and equipment and 2-3% of building value for buildings.
Depreciation = 13%. Fixed Cl + 3% Build ₦3.032 x 10^6
(ii). Local Taxes
1-4% of fixed capital investment (3%) ₦6.874 x 10^5
(iii).Insurance
0.4-1% of fixed capital investment (0.75%) ₦1.719 x 10^5
(iv). Rent
8-12% of value of fixed capital investment 10% ₦2.291 x 10^6
Total ₦6.182 x 10^6
Fixed capital investment = 15% TPC ₦4.12 x 10^7
B. Direct Production Cost:
i. Raw Materials
10-50% of total product cost (49%) ₦2.02 x 10^7
ii. Operating Labour (OL)
10-20% of total product cost (16%) ₦6.595 x 10^6
iii. Direct Supervisory and Clerical Labour (DS & CL)
10-25% of OL (25%) ₦1.649 x 10^6
iv. Utilities
10-20% of total product cost (18%) ₦7.419 x 10^6
v. Maintenance and repairs (M & R)
2-10% of fixed capital investment (7%) ₦1.604 x 10^6
vi. Operating Supplies
10-20% of M & R or 0.5-1% of FCI (18%M) ₦2.887 x 10^5
vii. Patent and Royalties
0-6% of total product cost (6%) ₦2.473 x 10^6
Total ₦4.154 x 10^7
C. Plant Overhead Costs
50-70% of operating labour, supervision, and maintenance or 5-15% of total product cost; includes for the following: general plant upkeep and overhead payroll overhead, packaging, medical, safety and protection, restaurants, salvage, laboratories, and storage facilities.
Considering the plant overhead cost to be 55% of OL, DS & CL and M & R
₦5.416 x 10^6
Manufacture cost = Direct production cost + Fixed charges + Plant overhead cost
₦5.314 x 10^7

II. General Expenses
A. Administrate costs
2-6% of total product cost (6%) ₦2.473 x 10^6
B. Distribution and Selling Costs
2-20% of total product cost (17%.) ₦7.007 x 10^6
C. Research and Development Costs
3% of total product cost ₦1.236 x 10^6
Total ₦1.072 x 10^7
III. Total Production Cost
Manufacture Cost + General Expenses ₦6.386 x 10^7
IV. Gross Earnings/Income
Selling Price = ₦300/tonne

Quantity = $3 \times 10^9 \frac{Kg}{yr}$

No of working days= 331 day
Total income ₦7.5 x 10^7
Gross income
Total income – Total Product Cost ₦1.114 x 10^7
Tax rate
15% of Gross income ₦16.71 x 10^6
Net profit ₦9.471 x 10^6

Rate of Return:

ROR = $\frac{Netprofit}{Total - CI} 100\%$ ROR = 37.236%

Pay Back Period:

PBP = $\frac{1}{ROR}$ yr = 2.686yrs

= 3yrs

Cash Flow

Cash Flow = Total income – T prod C ₦1.114 x 10^7

Net Present Worth

$$NPW = \sum_{i=1}^{n} \frac{Cash\_Flow}{(1+r)^n}$$

r = ROR ; n = 1
Therefore:

$$NPW = \sum_{i=1}^{n} \frac{Cash\_Flow}{(1+r)^n}$$ ₦8.119 x 10^6

Discounted Cash Flow Rate or Return

$$DCF = \sum_{i=1}^{n} \frac{Cash\_Flow}{(1+r)^n} = 0$$

r = 45% n := 65 DCFRR = 45%

$$DCF = \sum_{i=1}^{n} \frac{Cash\_Flow}{(1+r)^n}$$ DCF = 0

Return on Investment

ROI = 95.958%

REFERENCES

[1] Coulson, J.M. and Richardson, J.F; *Chemical Engineering, Volume 6;* Butterworth Heinemann; **1998**; Pg 604.
[2] Crompton, T.R., *Battery Reference Book*, Butterworth Heinemann, London, **1990**.

[3] Linden, D., *Handbook of Batteries*, Maiden Head, McGraw, **1995**.
[4] Linford, R.G., *Electro Chemical Science and Technology of Polymers*, Elsevier, New York, **1990**,
[5] Mantel, C.L., *Industrial Electrochemistry,* 3rd Edition, McGraw-Hill Book Company, (**1950**), Pg160 – 180.
[6] Perry, R.H, and Green D.W, *Perry's Chemical Engieneer's Handbook,* 7th Edition. McGraw-Hill Book Company, **1998**, Pg 19-16 to 19-35.
[7] Peters, M.S. and Timmerhaus, K.D., *Plant Design and Economics for Chemical Engineers,* 3rd Edition, McGraw-Hill Book Company, **1995**, Pg 147-209.
[8] Sinnot, R.K., *Chemical Engineering Design*. 2nd Edition, Volume 6, Butterworth Heinemann, **1993**, Pg 212-245.
[9] Urells, A.F., *Structural Inorganic Chemistry*, Oxford Claredon Press. **1995**.