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PRODUCTION AND ENGINEERING METHODS FOR CARB-TEK® BATTERIES IN FORK LIFT TRUCKS

JAMES C. SCHAEFER
ESB INCORPORATED
TECHNOLOGY CENTER
19 W. COLLEGE AVENUE
P. O. BOX 336
YARDLEY, PA. 19067

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FINAL REPORT VOLUME 3 – MANUFACTURING COST/PLANT LAYOUT ESTIMATE

PREPARED FOR
U. S. ARMY MOBILITY EQUIPMENT RESEARCH & DEVELOPMENT COMMAND
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)
This report describes the technological development of the Carb-Tek® Molten Salt Li/Cl system toward prototype production for eventual assembly into fork lift truck batteries. Engineering developments, cost reductions, and pilot line operations are described and discussed. Significant failure mode is attributed to certain cell components. Seals are a problem.

ABSTRACT

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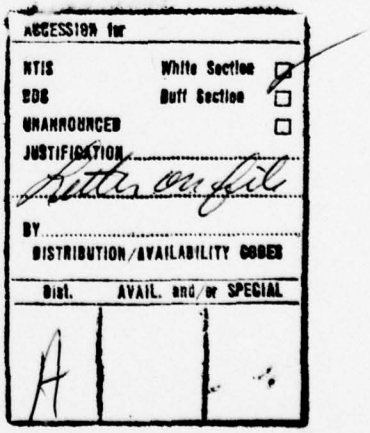

ESTIMATED MANUFACTURING COST AND PRELIMINARY PLANT LAYOUT FOR THE LITHIUM-TELLURIUM TETRACHLORIDE RECHARGEABLE MOLTEN SALT BATTERY

ESB INCORPORATED
YARDLEY, PA.

ESTIMATED MANUFACTURING COST AND
PRELIMINARY PLANT LAYOUT FOR THE LITHIUM-
TELLURIUM TETRACHLORIDE RECHARGEABLE MOLTEN SALT BATTERY

I. Summary

For a nominal 36 volt, 730 ampere-hour battery consisting of 48 MM-1 cells in series-parallel, the estimated factory cost (1000 batteries/year) is $10,239.06. The cost includes $1,448.83 for labor and overhead, $8,371.65 for materials, and allows $418.58 (5%) for material losses. The material cost is based on current prices with no projection for using as yet undeveloped lower cost materials.

The "best" projected factory cost is estimated at $3,931.98. This estimate is based on developing new and more economical materials and on a 10,000 batteries/year production rate. The estimated plant cost at the 10,000 batteries/year rate is $20,505,095.00. The estimated selling price of the battery is $4,844.60, which allows 11% for general and administrative costs and 11% for profit. For comparison, a lead-acid battery for the average 4000 lb lift truck sells for about $3,300.00. The estimated return on investment is 19.5%, which is insufficient to warrant commercial investment unless risk is eliminated.

A process flow sheet and a plant layout for the 10,000 batteries/year plant is attached to this report.

The cell system is based on the Standard Oil Company (Ohio) Carb-Tek^{R} concept and the modifications introduced by the ESB Technology Center group operating in the Standard Oil Company's facilities.

I. Introduction

This report updates the material cost and the manufacturing cost of the ESB June 1976 report for a 720 amp. hr. molten salt battery which employs cells composed of porous carbon cathodes with a tellurium tetrachloride additive, a lithium-aluminum alloy anode, and a eutectic mixture of potassium chloride and lithium chloride as electrolytes. The details of this battery design are described in the main body of the report.

The costs are based on the production of 10,000 batteries per year which is equivalent to 1,000 cells per shift assuming the following operating conditions for the plant:

A. 250 days per year

B. 5 days per week

C. 2 shifts per day

D. Two weeks shutdown per year for maintenance.

The present estimated material costs are based, for the most part, on the vendor's quotation for the common everyday materials. The more exotic materials, such as boron nitride and tellurium tetrachloride, are the vendor's best estimate based on possible breakthroughs in technology and/or volume production. This is the format for estimating material cost at the 1,000 and 10,000 battery per year level or Case I conditions shown in Table I.

Material costs were estimated on projections whereby the exotic materials would be replaced by new materials and/or components perhaps not even developed at this time, some of which are considered a possibility by some of our vendors. (Case II conditions also 10,000 batteries/year.) These new materials and/or components and their probable cost are as follows:

A. A boron nitride separator that utilizes the BN fibers more efficiently than the present mat separator or an entirely new separator material.

A vendor (Gaines Industries) has indicated a cost of $5.00 or less per cell for a potential (but unproven) substitute for BN.

B. A graphite collector to replace the grafoil for $1.00 per cell which is considered a possibility by one vendor (Gaines Industries).

C. A hot seal (feedthrough) for $10.00 per cell which would include the tungsten rod current carrier. This projection is based on information from one of our vendors (ILC) and the probably cost of the tungsten rod.

D. Aluminum at $0.50 per lb.

E. Lithium at $7.75 per lb.

F. Eutectic salt at $0.615 per lb.

The last three projected costs, 4, 5, and 6 , were adapted from Argonne National Laboratory Report ANL-76-12. The eutectic salt would be purified by electrolysis rather than purchasing the ultra pure salt from a vendor. The Case II material cost estimates are shown in Table II.

The total plant costs for the 10,000 batteries per year plant has been estimated by taking the estimated delivered equipment costs and multiplying them by various factors adapted from the article, "Cost Engineering in the Process Industries" by C. H. Chilton, 1960. The estimated equipment costs were obtained primarily from two sources: (1) vendors' estimated equipment cost, and (2) estimated equipment cost taken from Perry's Chemical Engineering Handbook, 4th Edition and adjusted to 1976 prices.

The resulting estimated total plant cost is strictly a "study estimate" or a preliminary estimate because of the minimum amount of data available for making the estimate. The breakdown is shown in Table IIIA and IIIB.

The direct labor estimates were calculated by conceptually breaking down the various manufacturing steps and estimating the amount of labor required. The factory costs shown in Table IVA and IVB were estimated assuming the following conditions:

A. Labor at $6.00 per hour

B. Fringe benefits at 30% of labor cost

C. Supervision, indirect labor, and indirect costs were assumed to be 200% of direct labor

D. Depreciation is for 15 years across the board and is calculated on a straight-line basis

E. 5% allowance for material losses.

Finally, the estimated selling price of the battery at a production rate of 10,000 per year was calculated by adding 11% to the factory cost for general and administrative costs plus another 11% for profit.

The plant layout was conceived as a 5,000 - 10,000 battery per year plant with consideration to material and personnel traffic flow consistent with convenient stocks near the assembly line. Areas for the various operations were adjusted to fit the residence-time in place to maintain a constant flow.

The dry box assembly areas are expected to have two-sided access for the external workers while provisions are included for human entry into the boxes for repair, remodeling, recovery of "lost" materials, etc. by means of locks and the use of space suits.

Land costs were taken from the prevailing rates in the Cleveland, Ohio area since it is the center for fork lift truck manufacturing and usage.

TABLE I

ESTIMATED MATERIAL COST

CASE I

Material	Amount Per MM-1 Cell	Amount Per Battery	Cost Per Battery (1,000)	Cost Per Battery (10,000)
1. Cold rolled low carbon steel sheet 18 ga.	5.38 lb.	258 lb.	45.64 $17.69/100#	45.64 $17.69/100#
2. Cold rolled low carbon steel flat stock 1/4" x 1 3/4" x 10 5/8"	1.32 lb.	64 lb.	23.78 $37.15/100#	23.78 $37.15/100#
3. Cold rolled low carbon steel flat stock 1/8" x 1 3/4" x 10 5/8"	.66 lb.	32 lb.	14.58 $45.55/100#	14.58 $45.55/100#
4. Aluminum sheet (.025")	1.94 lb.	93 lb.	83.70 $.90/#	83.70 $.90/#
5. Lithium Foil (.020")	.37 lb	18 lb	567.00 $31.50/#	522.00 $29.00/#
6. 304 S/S Screen 100 mesh x .0045" wire diameter	.56 lb.	27 lb.	153.90 $5.70/#	153.90 $5.70/#
7. Separator	.22 lb.	11 lb.	550.00 $50.00/# (BN)	550.00 $50.00/# (BN)
8. Carbon 30 x 140 mesh	4.8 lb.	230 lb.	195.50 $.85/#	195.50 $.85/#
9. Graphite	.2 lb.	10 lb.	59.04	59.04
10. High Density Grafoil .030" x 10 13/16" x 12 3/8"	.28 lb.	14 lb.	955.20 $19.90 ea.	955.20 $19.90 ea.
11. Eutectic Salt	8.5 lb.	408 lb.	999.60 $2.45/#	999.60 $2.45/#
12. Durite Resin	1.2 lb.	58 lb.	33.64 $.58/#	33.64 $.58/#

TABLE I (Continued)

ESTIMATED MATERIAL COST

CASE I

	Material	Amount Per MM-1 Cell	Amount Per Battery	Cost Per Battery (1,000)	Cost Per Battery (10,000)
13.	$TeCl_4$ 99.7%	1.33 lb.	64 lb.	1280.00 $20.00/#	896.00 $14.00/#
14.	430 S/S clad OFHC Copper Bus Bars 1/2" x 1 1/2" x 8" - 24	430 S/S	16 lb.	23/20 $1.45/#	23.20 $1.45/#
	1/2" x 1 1/2" x 6" - 13	Cu	47 lb.	131.13 $2.79/#	131.13 $2.79/#
15.	Battery Tray 1/4" cold rolled steel	$19.80/100#	108 lb.	21.38	21.38
	7 Ga cold rolled steel	$17.55/100#	58 lb.	10.18	10.18
16.	Heaters (Olate), 2		66 lb.	384.00 $16.00 ea.	384.00 $16.00 ea.
17.	Heat insulating 5% of total	--		418.58	307.58
18.	Electrical insulation .015" thickness mica paper 40 ft^2	--	7.2 lb.	21.60 $.54/$ft^2$	21.60 $.54/$ft^2$
19.	Hot Seal	.33 lb.	16 lb.	2400.00 $50.00/seal	720.00 $15.00/seal
			Total	$8,371.65	$6,151.65

TABLE II

ESTIMATED MATERIAL COST

CASE II

	Material	Cost Per Battery (10,000)
1.	Cold rolled low carbon steel sheet 18 ga.	45.64 $17.69/100#
2.	Cold rolled low carbon steel flat stock 1/4" x 1 5/8" x 10 5/8"	23.70 $37.15/100#
3.	Cold rolled low carbon steel flat stock 1/8" x 1 5/8" x 10 5/8"	14.58 $45.55/100#
4.	Aluminum sheet (.025")	46.50 $ .50/#
5.	Lithium Foil (.020:)	139.50 $7.75/#
6.	304 s/s Screen 100 mesh x .0045" wire diam.	153.90 $5.70/#
7.	Separator	240.00 $5.00/cell
8.	Carbon 30 x 140 mesh	195.50 $ .84/#
9.	Graphite	59.04
10.	High Density Grafoil .030 x 10 13/16 x 12 3/8	48.00 $1.00/cell
11.	Eutectic Salt	257.04 $ .63/#
12.	Durite Resin	33.64 $ .58/#
13.	$TeCl_4$ 99.7%	800.00 $12.50/#
14.	430 s/s clad OFHC Copper Bus Bars 1/2" x 1 1/2" x 8" -24 1/2" x 1 1/2" x 6" -13	131.13 $2.79/#

TABLE II Continued

ESTIMATED MATERIAL COST

CASE II

	Material		Cost Per Battery (10,000)
15.	Battery Tray 1/4" cold rolled steel 7 ga. cold rolled steel		21.38 10.18
16.	Heaters (plate), 2 per module		384.00 $16.00/ea.
17.	Heat Insulation: 5% of total		$163.44
18.	Electrical Insulation .015" thickness mica paper 40 ft^2		21.60 $ .54/ft^2
19.	Hot Seal		480.00 $10.00 ea.
		TOTAL	$3,268.85

TABLE IIIA

ESTIMATED TOTAL PLANT COST

ESTIMATED EQUIPMENT COST:

	Equipment	
1.	Dry Boxes (VAC)	$ 2,658,500.00
2.	Formation Tanks 30 @ $5,400.00 each	162,000.00
3.	Formation Heaters	50,000.00
4.	Dump Tank 30 @ $4,175.00 each	125,250.00
5.	Dump Tank Heaters	50,000.00
6.	Cyclers $1000/cathode x 1000 cathodes x 2 days	2,000,000.00
7.	Shears (Lithium)	2,000.00
8.	Shears (Screen)	2,000.00
9.	Cutters for Tubing	2,000.00
10.	Cutters for bus bars	2,000.00
11.	Vacuum pumps for heat treatment 1000 CFM	15,000.00
12.	Vacuum pumps for salt fill 300 CFM	8,000.00
13.	Welders for Cans (20)	20,000.00
14.	Helium Leak Detectors (50)	200,000.00
15.	Transfer Mechanisms Overheads) Bars) Belts)	750,000.00
16.	Shears for can blank	4,000.00
17.	Shear and punch for tops and bottoms	14,000.00
18.	Power brake for forming cans	8,000.00
19.	Vacuum Bake-out Furnaces 8 @ $20,400 each	163,200.00
20.	Vacuum $TeCl_4$ Impregnating Furnaces 4 @ $20,400 each	81,600.00
21.	$TeCl_4$ Vapor Furnace 4 @ $6,732.00 each	26,925.00
	Total Estimated Equipment Cost	$ 6,344,475.00

TABLE IIIA (Continued)

ESTIMATED TOTAL PLANT COST*

ESTIMATED DELIVERED EQUIPMENT COST:	
Equipment Cost	$ 6,344,475.00
Freight (1% of equipment cost)	63,445.00
Delivered Equipment Cost	$ 6,407,920.00
ESTIMATED INSTALLED EQUIPMENT COST:	
Delivered Equipment Cost	$ 6,407,920.00
Installation Cost (25% of delivered equipment cost)	1,601,980.00
Installed Equipment Cost	$ 8,009,900.00
ESTIMATED TOTAL PHYSICAL COST:	
Installed Equipment Cost	$ 8,009,900.00
Piping (5% of installed equipment cost)	400,495.00
Instrumentation (5% of installed equipment cost)	400,495.00
Manufacturing Building (60% of installed equipment cost)	4,805,940.00
Auxiliary Facilities (25% of installed equipment cost)	2,002,475.00
Estimated Total Physical Cost Total	$15,619,305.00

* NOTE - Above factors adapted from "Cost Engineering in the Process Industries," C. H. Chilton, McGraw-Hill (1960).

TABLE IIIA (Continued)

	Batteries/Year 10,000	1,000
ESTIMATED TOTAL PLANT COST:		
Estimated Total Physical Cost	$ 15,619,305.00	
Engineering & Construction (20% of total physical cost)	3,123,860.00	
Contingency (10% of total physical cost)	1,561,930.00	
Estimated Total Plant Cost (excluding land)	$ 20,305,095.00	*$5,100,410.00
Land, 10 A @ $20,000/A (Cleveland area)	200,000.00	200,000.00
Estimated Total Plant Cost (Including land)	$ 20,505,095.00	$5,300,410.00

*Estimated total plant cost (excluding land) for 1,000 batteries per year is calculated as follows:

$$\frac{C_A}{C_B} = \left(\frac{P_A}{P_B}\right) \quad 0.6$$

Where C_B is the estimated total plant cost for producing 10,000 batteries per year (P_B) and the estimated total plant cost (C_A) for 1000 batteries per year (P_A) is calculated from C_B by this formula.

$$\text{Cost} = \$20,305,095.00 \times \left(\frac{1,000}{10,000}\right) \quad 0.6$$

Cost = $5,100,410.00

TABLE IIIB

*FACTORS FOR ESTIMATING TOTAL PLANT COSTS

Expressed as Percentages of Installed Equipment Cost"

PIPING	5%
INSTRUMENTATION	5%
MANUFACTURING BUILDING	60%
AUXILIARY FACILITIES	25%

Expressed as Percentages of Total Physical Cost:

ENGINEERING AND CONSTRUCTION	20%
CONTINGENCY	10%

Building costs include service facilities, such as heating, ventilation, sanitary plumbing, lighting, and equipment supports where such supports are an integral part of the structure.

Electrical facilities are not shown separately. Motors, starters, and wiring for equipment are included in installed equipment costs. Electrical services within building are included with building costs.

Substation and transformer costs come under auxiliary facilities.

*NOTE - Above factors adapted from "Cost Engineering In the Process Inudstries," C. H. Chilton, McGraw-Hill, (1960).

TABLE IVA

ESTIMATED DIRECT LABOR

	Operation	Batteries/Year 10,000 Men/Shift	1,000 Men/Shift
1.	Cathodes - Storage to Formation	4	1
2.	Cathode Formation	6	1
3.	Anode Fabrication	4	1
4.	Metal Cutting, Fabricating and Cleaning	7	3
5.	Cell Assembly (before welding)	4	1
6.	Welding	5	2
7.	Cell Cycling and Testing	2	1
8.	Fabricate Bus Bars, Interconnections, etc. for Battery	4	1
9.	Fabricate and Weld Steel Tray for Battery	4	1
10.	Assemble Battery	4	1
11.	Battery Testing	1	1
	Total Men Per Shift	46	14
	Two Shifts (10,000 Batteries)	92	28

Total Direct Labor Costs:

$$10{,}000 \quad \frac{92 \text{ men}}{\text{day}} \times \frac{250 \text{ days}}{\text{year}} \times \frac{8 \text{ hrs}}{\text{day}} \times \frac{\$6.00}{\text{hour}} = \$1{,}104{,}000.00/\text{year}$$

$$1{,}000 \quad \frac{28 \text{ men}}{\text{day}} \times \frac{250 \text{ days}}{\text{year}} \times \frac{8 \text{ hrs}}{\text{day}} \times \frac{\$6.00}{\text{hour}} = \$336{,}000.00/\text{year}$$

TABLE IVB

MANUFACTURING COST ESTIMATE

	Batteries/year 10,000	1,000
LABOR & OVERHEAD COST (Annual):		
Direct Labor	$1,104,000.00	$ 336,000.00
Overhead		
Fringe Benefits (30%)	331,200.00	100,800.00
Supervision, Indirect Labor and Indirect Operating Costs (2 x direct labor)	2,208,000.00	672,000.00
Depreciation (Straight-line, 15 years)	1,353,673.00	340,030.00
Total Labor and Overhead	$4,996,873.00	$1,448,830.00
FACTORY COST (Per Battery):		
Labor and Overhead	499.69	1,448.83
Materials	3,268.85	8,371.65
Material Losses, 5%	163.44	418.58
Total Factory Cost	$ 3,931.98	$10,239.06
BATTERY PRICE:		
Factory Cost	3,931.98	10,239.06
General & Administrative, 11%	432.52	1,126.30
Subtotal	$ 4,364.50	$11,365.36
Profit, 11%	480.10	1,250.19
Battery Price	$ 4,844.60	$12,615.55

TABLE IVB (Continued)

INVESTMENT COST SUMMARY

	Batteries/Year 10,000	1,000
Total Plant Cost	$ 20,305,095.00	$5,100,410.00
Land, 10 A @ $20,000/A (Cleveland Area)	200,000.00	200,000.00
Inventory and Work in Progress (20% of total plant cost)	4,061,019.00	1,020,082.00
Subtotal	24,566,114.00	6,320,492.00
Other Cash Requirements	1,000.000.00	250,000.00
TOTAL	$25,266,114.00	$6,570,492.00

10,000 $\quad ROI = \frac{480.10 \times 10,000}{\$24,566,114.00} \times 100\% = 19.5\%$

1,000 $\quad ROI = \frac{\$1250.19 \times 1,000}{\$6,320,492.00} \times 100\% = 19.8\%$