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DATE: April 3, 1956

SUBJECT: Estimate of the Cost of Producing Nitrogen 15 by Chemical
Exchange: Ammonia-Ammonium Carbonate System Using Calcium
Hydroxide Reflux Assuming Losses of 0.001 at Each Reflux Point

TO: H. M. McLeod, Jr.

FROM: B. B. Klima and W. T. Ward

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INTRA-LABORATORY CORRESPONDENCE

OAK RIDGE NATIONAL LABORATORY

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April 3, 1956

To: H. M. McLeod, Jr.

From: B. B. Klima and W. T. Ward

Re: Attached Report on Cost of Nitrogen 15

The attached report was prepared in January, 1955, so as to indicate the effect of losses on product cost using the Ammonia-Ammonium Carbonate system (with CaOH_2 reflux) for nitrogen 15 production. Before the report was issued attention was directed toward the Nitrox system. However, since the figures for this estimate are on hand and since the cost "scale-up" factors due to the loss will be roughly applicable to other systems, it is felt that the material should be issued as a matter of record. Please consider this report as supplemental to the material appearing in document ORNL-CF-55-1-20, "Estimate of the Cost of Producing Nitrogen 15 by Chemical Exchange: Ammonia-Ammonium Carbonate System Using Calcium Hydroxide Reflux."

B. B. Klima

W. T. Ward

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ESTIMATE OF THE COST OF PRODUCING NITROGEN 15BY CHEMICAL EXCHANGE

AMMONIA-AMMONIUM CARBONATE SYSTEM
USING CALCIUM HYDROXIDE REFLUX
ASSUMING LOSSES OF 0.001 AT EACH REFLUX POINT

Introduction

A cost estimate was made to determine the extent to which a loss of 0.001 mole fraction of the nitrogen refluxed at each product(a) reflux point would affect the plant cost and unit cost of product in a nitrogen 15 separation plant using the ammonium carbonate process. The loss of 0.001 was used as a basis for this estimate since it was found that this was a maximum loss found in the laboratory and it was assumed that the effect of losses of a more moderate nature could be interpolated using this report and the no loss cost estimate made previously(b). The optimum cascade, based on these losses, was calculated by Dr. W. C. DeMarcus of the Operations Analysis Division of the K-25 plant.(c) The plant designed for the cost estimate was based on this optimum cascade and the chemical process used in Case I of the no loss estimate.()

The cost of producing the nitrogen 15 isotope (95 percent isotopic purity), if a loss of 0.001 occurs at each reflux point, is 47 percent greater at a production rate of one pound per day and 69 percent more at a production rate of fifty pounds per day (see Figure 1 and Table 1).

-
- a. Technically, the only "product" refluxer is that one which refluxes product level material, which in this plant is the refluxer for the aqueous phase from the fourth enrichment section. However, since the refluxing process for the aqueous streams removed from the first, second, and third enrichment sections is identical to that for the aqueous stream from the fourth enrichment section, all four of these refluxers are hereinafter called product refluxers.
- b. B. B. Klima and W. T. Ward, Estimate of the Cost of Producing Nitrogen 15 by Chemical Exchange--Ammonia-Ammonium Carbonate System Using Calcium Hydroxide Reflux, ORNL CF-55-1-20, January 12, 1955.
- c. W. C. DeMarcus, and J. N. Dyer, "Ideal" Cascades with Imperfect Refluxers, KD-996, July 29, 1954.

FIGURE 1- COMPARISON OF NITROGEN 15 PRODUCTION COSTS WITH AND WITHOUT LOSSES AT EACH PRODUCT REFLUXER.

798 003

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TABLE 1. EFFECT OF 0.001 LOSS OF INPUT NITROGEN IN
EACH PRODUCT REFLUXER ON PLANT INVESTMENT AND
PRODUCT COST USING SAME PROCESS

	<u>One Pound per Day</u> <u>Production Rate</u>		<u>50 Pounds per Day</u> <u>Production Rate</u>	
	<u>No Loss¹</u>	<u>0.001 Loss</u>	<u>No Loss¹</u>	<u>0.001 Loss</u>
Installed Equipment Cost	\$ 624,560	\$ 986,100	\$ 7,377,095	\$11,647,488
Total Plant Investment	3,251,240	5,121,691	38,638,590	61,264,656
Total Annual Operating Costs	1,465,256	2,157,705	19,684,755	33,338,594
Cost per pound of nitrogen 15	4,014	5,912	1,079	1,827
Cost per gram of nitrogen 15	\$8.85	\$13.03	\$2.38	\$4.03

1. ORNL 55-1-20, Case I.

700 86%

DESCRIPTION OF THE PROCESS

The process for the ammonia-ammonium carbonate system used in this report is the same as the process used for the no loss estimate.* The process description, therefore, includes only the highlights of the process and the few points where there are differences between the two estimates. A schematic flow diagram of the process is shown in Figure 2.

The isotopic exchange takes place between an aqueous ammonium carbonate solution and a gaseous ammonia phase as shown by the following equation:

A saturated ammonium carbonate solution at the specified operating temperature of 30°C is about 6 molar in $\text{CO}_3^{=}$. This solution will dissolve about six additional moles of NH_3 per liter, so that the concentration of the aqueous phase throughout the exchange system is approximately as follows:

NH_4^+ = 6 gram moles per liter

COONH_2^- = 6 gram moles per liter

Dissolved NH_3 = 6 gram moles per liter

The exchange system consists of a series of columns through which the aqueous solution of ammonium carbonate and the gaseous ammonia flow countercurrently. It is divided into a stripping section and four consecutive enrichment sections, in each of which the flow is smaller than in the preceding one. The aqueous stream that is removed from the exchange system at each of the three points that the system is tapered, and the entire aqueous stream from the smallest enrichment section are sent to separate product type refluxers where they are decomposed. The resulting gaseous ammonia from each refluxer is returned to the same respective enrichment section (at the same point) from which the aqueous phase was removed. A small portion of the ammonia stream from the smallest product refluxer is removed as product.

Each product refluxer consists of a column supplied with steam from a reboiler. The aqueous phase from the exchange

*ORNL CF-55-1-20, Case I.

system is fed at a point part way up the column, as approximately 30 stages are required below the feed point to reduce the ammonia concentration of the liquid to 1 ppm and approximately 13 stages are needed above the feed point to reduce the carbon dioxide content of the gas to 1 ppm. A slurry of calcium hydroxide is admitted to the top of the column to scrub out the carbon dioxide. The reactions taking place in the column are essentially as follows:

Calcium hydroxide slurry is supplied to all of the product reflux columns from one slaker. All of the equipment processing slurries (except the slaker) is installed in duplicate.

The gaseous ammonia from the stripping section of the exchange system is divided three ways, as follows:

- (1) A waste stream is removed from the system.
- (2) One-third of the remainder is sent to the first waste reflux column to react with water to form NH_4OH .
- (3) The other two-thirds are sent to the third waste reflux column to react with the ammonium bicarbonate solution from the second column and to saturate that solution with ammonia.

The reactions that take place in the waste reflux system may be shown as follows:

The calcium carbonate from the product refluxers is filtered, dried, and calcined to form lime, which is then slaked for use in the produce refluxers. A sufficient amount of the stack gas from the calciner (rich in carbon dioxide) is cooled, scrubbed and sent to the second waste reflux column, where it supplies the carbon dioxide required for that reaction.

BASES OF THE DESIGN

The plant was designed to produce one pound per day of nitrogen 15 (95 percent isotopic purity). This cost was then scaled up (same methods used as in Appendix H of ORNL CF-55-1-20) to a production rate of fifty pounds per day.

The tapered cascade around which the plant was designed is based on the optimum cascade resulting from calculations by DeMarcus and Dyer. The data for this optimum cascade are presented in Fig. A-1 in Appendix A.

The criteria used as bases for the design are the same as those described for Case I in ORNL CF-55-1-20, with the exception of the following:

(1) Losses

A loss of 0.001 mole fraction of the incoming nitrogen at each product reflux point is assumed. (Complete reflux, i.e., no losses, was assumed in ORNL CF-55-1-20).

(2) Taper of Plant

There are four enrichment exchange sections of decreasing capacities in series. (Three enrichment exchange sections were assumed in ORNL CF-55-1-20).

(3) Flow Rates

Changes in Items 1 and 2 result in different flow rates for this estimate. (The liquid and vapor flow rates were based on data given in Appendix A and the calculations are found in Appendix B).

(4) Number of Stages (Length of Columns)

The number of stages required and the resulting length of columns are different due to the changes in Items 1 and 2. (The number of stages are given in Appendix A. The calculations to determine the length of columns are found in Appendix B).

(5) Feed Assay (mol fraction N^{15})

Feed assay (normal nitrogen) of 0.0038 mole fraction N^{15} was used in ORNL CF-55-1-20. However, DeMarcus used 0.0037 in the calculation of the optimum cascade; therefore, it is used in this estimate.

COST ESTIMATING PROCEDURE

The methods used to estimate the total plant investment and the operating costs are essentially the same as in ORNL CF-55-1-20. A description of the method is given in Appendix D. The method used to scale up the cost of the plant to produce one pound per day to one producing fifty pounds per day is also given in Appendix D.

COST ESTIMATE

The cost of producing one pound per day of the nitrogen 15 isotope (95% isotopic purity), assuming a loss of 0.001 mole fraction of the incoming nitrogen at each product refluxer, is estimated to be \$5,912. For a plant producing fifty pounds per day this cost drops to \$1,827 per pound. These costs are approximately 47 percent and 69 percent higher, respectively, than for plants of the same capacities designed on the basis of perfect (no loss) reflux.

A breakdown of the investment costs, the fixed costs and the variable costs are given in Tables 2, 3, and 4, respectively. A summary of annual operating costs including the cost per pound and per gram of nitrogen 15 produced is given in Table 5.

TABLE 2. INVESTMENT COST SUMMARY

	One pound per day plant	Fifty pounds per day plant
A Installed equipment cost	\$ 986,100 ¹	\$11,647,488 ²
B Process piping (0.6 A)	591,660	6,988,493
C Instrumentation (0.14 A)	138,054	1,630,648
D Process buildings (0.3 A)	295,830	3,494,246
E Laboratory furniture and equipment (0.03 A)	29,583	349,425
F Service facilities (0.3 A)	295,830	3,494,246
G Total Physical Plant (A+B+C+D+E+F)	\$2,337,057	\$27,604,546
H Engineering cost (0.4 G)	934,823	11,041,818
I Site development (0.15 A)	147,915	1,747,123
J Preoperational cost (0.4 G)	934,823	11,041,818
K Contingency (0.25 G)	584,264	6,901,137
L Working capital	182,809 ²	2,928,214 ²
M Total plant investment (G+H+I+J+K+L)	\$5,121,691	\$61,264,656

1. See Appendix B for details.

2. See Appendix E for details.

TABLE 3. FIXED COST SUMMARY

N-1 Investment costs per year		
a. Depreciation $[0.15(M-L)]$	\$ 740,832	\$ 8,750,466
b. Interest on fixed capital $[0.01(M-L)]$	49,389	583,364
c. Interest on working capital (0.01 L)	1,828	29,282
d. Payment in lieu of taxes $[0.01(M-L)]$	49,389	583,364
N-2 Overhead $[(0-4) + (0-5) + 0.7$ $(0-2)]$ Cost per year	404,478	4,415,620
Total annual fixed costs $[(N-1) +$ $(N-2)]$	\$1,245,916	\$14,362,096

TABLE 4. VARIABLE COST SUMMARY

	One pound per day plant	Fifty pounds per day plant
0-1 Raw materials	\$218,208 ¹	\$10,910,400 ²
0-2 Direct labor and supervision (\$3.00/man hr)	394,200 ¹	4,139,100 ²
0-3 Utilities (0.06 G)	140,223	1,656,273
0-4 Maintenance (0.05 G)	116,853	1,380,227
0-5 Supplies (0.005 G)	11,685	138,023
0-6 Packaging, storage, shortage, etc. 0.05 [(0-1) + (0-2)]	30,620	752,475
0-7 Total annual variable costs [(0-1) + (0-2) + (0-3) + (0-4) + (0-5) + (0-6)]	\$911,789	\$18,976,498

1. See Appendix C for details.

2. See Appendix E for details.

TABLE 5. OPERATING AND PRODUCT COSTS SUMMARY

	One pound per day plant	Fifty pounds per day plant
Total fixed costs per year	\$1,245,916	\$14,362,096
Total variable costs per year	\$ 911,789	\$18,976,498
Total operating costs per year	\$2,157,705	\$33,338,594
Total operating cost per day	\$ 5,912	\$ 91,339
Total operating cost per pound of nitrogen 15 produced	\$ 5,912	\$ 1,827
Total operating cost per gram of nitrogen 15 produced	\$13.03	\$4.03

APPENDIX A- OPTIMUM CASCADE

The optimum cascade for the ammonia-ammonium carbonate system assuming losses of 0.001 of the molar input of nitrogen to each product type refluxer was calculated by Dr. W. C. De Marcus of the Operational Analyses Division of K-25. A diagram of the cascade is shown in Figure A-1. The data from this diagram were used as part of the bases for the design of the enrichment exchange section of the plant.

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FIGURE A-1. OPTIMUM CASCADE

APPENDIX B - EQUIPMENT CALCULATIONS

To Determine Cascade Flow Rates - Enrichment Section

Section IV $P = 1 \text{ lb per day of } N^{15} = \frac{1}{.95} = 1.0526 \text{ lbs/day of } 95\% N^{15}$

$$\frac{V}{P} = 150 ; V = 150 (1.0526) = 157.89 \text{ lbs/day Total N}$$

in aqueous phase

$$\frac{157.89 (453.6)}{14.95 (24) (60)} = 3.3268 \text{ gram moles/min - Ag.}$$

$$\frac{3.3268}{18} = 0.185 \text{ liters/min or } 0.04883 \text{ gal/min - Ag.}$$

$$\text{Loss at end of Section} = 0.001 (3.3268) = 0.0033 \text{ gm moles/min}$$

$$\text{Product withdrawal} = \frac{1.0526 (453.6)}{14.95 (24) (60)} = 0.0222 \text{ gm. moles/min}$$

$$\text{Gas flow} = 3.3268 - (0.0222 + 0.0033) = 3.3013 \text{ gm moles/min.}$$

$$= \frac{3.3013 (22.4) (303)}{28.3 (273)} = 2.900 \text{ cu ft/min @ } 30^\circ\text{C}$$

Section III

$$\frac{V}{P} = 1800 ; V = 1800 (1.0526) = 1894.7 \text{ lbs/day Total N}$$

in Aqueous Phase

$$\frac{1894.7 (453.6)}{14.95 (1440)} = 39.9218 \text{ gram moles/min.}$$

$$\frac{39.9218}{18} = 2.2179 \text{ liters/min. or } \frac{2.2179}{3.785} = 0.586 \text{ gal/min}$$

Ag. Phase

W TW 9/21/54
✓ R R W 11/22/54
cp R R W 11/5/55

$$\text{Total loss above Sect III} = 0.001(39.9218) = 0.0399 \text{ gr. moles/min.}$$

$$\text{Gaseous Flow} = 39.9218 - (0.0399 + 0.0222) = 39.8597 \text{ gr. moles/min.}$$

$$\frac{39.8597(22.4)(303)}{28.3(273)} = 35.017 \text{ cu ft./min @ } 30^\circ\text{C}$$

Section II

$$\frac{V}{P} = 10,000; V = 10,000(1.0526) = 10,526 \text{ lbs/day Total N in aqueous phase}$$

$$\frac{10,526(453.6)}{14.95(1440)} = 221.7853 \text{ gram moles/min.}$$

$$\frac{221.7853}{18^m} = 12.3214 \text{ liters/min. or } 3.255 \text{ gal/min.}$$

$$\text{Total loss above section II} = 0.001(221.7853) = 0.2218 \text{ g. moles/min.}$$

$$\text{Gaseous Flow} = 221.7853 - (0.0222 + 0.2218) = 221.54 \text{ g. moles/min.}$$

$$\frac{221.54(22.4)(303)}{28.3(273)} = 194.62 \text{ cu ft./min. at } 30^\circ\text{C}$$

Section I

$$\frac{V}{P} = 50,000; V = 50,000(1.0526) = 52,630 \text{ lbs/day Total N in Aqueous Phase}$$

$$\frac{52,630(453.6)}{14.95(1440)} = 1,108.9264 \text{ gram moles/min.}$$

$$\frac{1108.9264}{18^m} = 61.607 \text{ liters/min or } 16.277 \text{ gal/min.}$$

$$\text{Total loss above Sect. I} = 0.001(1108.9264) = 1.1089 \text{ g. moles/min.}$$

$$\text{Gaseous Flow} = 1,108.9264 - (1.1089 + 0.0222) = 1107.7953 \text{ g. moles/min.}$$

$$\frac{1107.8(22.4)(303)}{28.3(273)} = 973.20 \text{ cu ft./min @ } 30^\circ\text{C}$$

WTW 9/21/54
✓ RRW 11/22/54
cpd BBE 11/5/55

Summary of Flow Rates - Enrichment Section

	Section <u>I</u>	Section <u>II</u>	Section <u>III</u>	Section <u>IV</u>
Aqueous gal./min.	16.28	3.255	0.586	0.0488
gram moles/min	1108.9	221.79	39.922	3.3268
Gaseous Cuft./min.	973.2	194.6	35.02	2.900
gram. moles/min.	1107.8	221.54	39.860	3.3013

To Determine Cascade Flow Rates - Stripping Section

In order to make this cascade comparable with the cascade in the ammonia-ammonium carbonate report (Zero loss) (ORNL-CF-55-1-20) the flows in the stripping section were calculated for three different feed rates. Since these flows did not give a waste stream of the same composition as used in that report, the three values obtained were plotted in figure B-1. From this curve a fourth value of the feed was chosen at point number 4 and this value was used in the stripping calculations. This value was acceptably close to the desired value and was used as a basis for the stripping section flows.

WTW 9-22-54
✓ RRW 10-22-54
cfd BBK 1-5-55

Given: $P = 0.0222$ gram moles/minute

$$L_1 = 1.108926 - 0.221785 = 0.887141 \text{ gram moles/min Loss Sect 1}$$

$$L_2 = 0.221785 - 0.039922 = 0.181863 \text{ gram moles/min Loss Sect 2}$$

$$L_3 = 0.039922 - 0.003327 = 0.036595 \text{ gram moles/min Loss Sect 3}$$

$$L_4 = 0.003327 \text{ gram moles/min. Loss Sect 4.}$$

$$y_P^{14} = y_4^{14} = 0.05; y_3^{14} = 0.4756; y_2^{14} = 0.93985; y_1^{14} = 0.985;$$

$$y_F^{14} = 0.9963$$

$$y_W^{14} = \text{should be } 0.9983$$

Solve The following equations simultaneously by solving number one for W by substituting values of F . Using these values of W solve equation two for y_W^{14} .

$$\text{Equation 1: } W = F - (P + L_1 + L_2 + L_3 + L_4)$$

$$\text{Equation 2: } y_W W = y_F F - (y_P P + y_1 L_1 + y_2 L_2 + y_3 L_3 + y_4 L_4)$$

Substitution of Knowns in Equation 1:

$$W = F - (0.0222 + 0.8871 + 0.1819 + 0.0366 + 0.0033)$$

$$W = F - 1.1311$$

Substitution of Knowns in Equation 2:

$$y_W W = (0.9963)F - [(0.05)(0.0222) + (0.985)(0.887141) + (0.93985)(0.181863) + (0.4756)(0.036595) + (0.05)(0.003327)]$$

$$y_W W = (0.9963)F - [0.00111 + 0.873834 + 0.170924 + 0.017405 + 0.000166]$$

$$y_W W = 0.9963F - 1.06344$$

Trial Number	1	2	3	4
F grammoles/min (assumed)	20	50	40	34
W gram moles/min (determined)	18.8689	48.8689	38.8689	32.8689
y_W^{14} mol. fr. (determined)	0.999664	0.997599	0.997933	0.998231
y_W^{15} mol. fr. (by diff.)	0.000336	0.00240	0.002067	0.00177

WTW 9-22-54
✓RRW 11-22-54
cpt B BK 1-5-55

FIGURE B.1

To determine number of Stages required Stripping Section

$$V_W = V_S = 1107.7953 + 34 = 1141.7953 \text{ gr. moles/min.}$$

$$\frac{W}{V_S} = \frac{32.8689}{1141.8} = 0.028787034$$

$$(V_W - W)X_B = V_W y_F - W y_w$$

$$(1141.7953 - 32.8689)X_B = (1141.7953)(0.9963) - (32.8689)(0.998231)$$

$$1108.9264 X_B = 1137.5706574 - 32.8107549 = 1104.7599$$

$$X_B = \frac{1104.7599}{1108.9264} = 0.99624276$$

$$A = \frac{1}{\psi} = 50$$

$$B = \frac{1 + \psi \left(1 - \frac{W}{V_S} y_w\right)}{\psi \left(1 - \frac{W}{V_S}\right)} = \frac{1 + 0.02 [1 - (0.028787034)(0.998231)]}{0.02 [1 - 0.028787034]}$$

$$B = 52.482065$$

W.T.W. - 9-22-54
 ✓ R.R.W. - 11-22-54
 C.P.D. B.B.K. - 1-5-55

$$C = \frac{(0.028787034)(0.998231)}{0.02(1 - 0.028787034)} = 1.47939278$$

$$B - A = 52.482065 - 50 = 2.482065$$

$$(B - A)^2 = 6.1606467$$

$$4C = 4(1.47939278) = 5.9175711$$

$$X_1 = \frac{2.482065 + \sqrt{6.1606467 - 5.9175711}}{2} = 1.487546$$

$$X_0 = \frac{2.482065 - 0.493027}{2} = 0.994519$$

$$\left[\frac{1 + (0.02)(1.487546)}{1 + (0.02)(0.994519)} \right]^{N_s} = \left[\frac{0.998231 - 0.994519}{1.487546 - 0.998231} \right] \left[\frac{1.487546 - 0.99624276}{0.99624276 - 0.994519} \right]$$

$$1.0096682^{N_s} = 2.1618805$$

$$N_s \log 1.0096682 = \log 2.1618805$$

$$N_s = \frac{\log 2.1618805}{\log 1.0096682} = \frac{0.3348349}{0.0041773} = 80.2 \text{ stages required in the stripping section.}$$

Summary of Flow Rates - Stripping Section

Aqueous - 16.277 gal./min
1108.9264 gram moles/min.

Gaseous - 1103.07 cu ft/min,
1141.7953 gram moles/min.

Packing Characteristics

Packing	Use in Columns inches diam.	Flooding Rate ft/sec	Design - 70% Flooding ft/sec
1" Intalox Saddles	6 to 12	7.31	5.12
1/2" Intalox Saddles	3 to 6	4.39	3.07
1/4" Rashig Rings	1 1/2 to 3	2.31	1.62

Packing	Col. Diam inches	Area sq. ft.	Max. Throughput cuft./min.
1" Intalox Saddles	12	0.7972	245
" " "	10	0.5475	168
" " "	8	0.3474	107
" " "	6	0.2006	62
1/2" Intalox Saddles	6	0.2006	36.9
" " "	5	0.1390	25.6
" " "	4	0.0884	16.3
" " "	3 1/2	0.0687	12.6
" " "	3	0.0513	9.45
1/4" Rashig Rings	2 1/2	0.03322	3.23
" " "	2	0.02330	2.26
" " "	1 1/2	0.01414	1.37

Bubble Cap Column Characteristics

13" Plate Spacing - Ideal "G" = ~ 582.6

Col. Diam inches	Max Flow cuft./min
18	364
20	448
24	650
30	1026

INTW 9-22-54
✓ RRW 11-22-54
cpd BTK 1-5-55

To Determine Size and Cost of Exchange Columns

Section IV - Enrichment

Gaseous phase rate = 2.900 cuft./min

Col. Diameter = 2 1/2" - 1/4" Raschig Rings

Stage Length = 0.6 ft (minimum)

Number of Stages = 223.3

Column Height = 223.3 (0.6) = 134 ft.

Cost = 1.093 (\$27.50/ft) (134 ft) = \$4,030.

Section III - Enrichment

Gaseous phase rate = 35.02 cuft./min.

Col. Diameter = 6" - 1/2" Intalox Saddles

Stage Length = 9" = 0.75 ft

Number of Stages = 250

Column Height = 250 (0.75) = 187.5 ft.

Cost = 1.093 (\$42.00/ft) (187.5 ft) = \$8610.

Section II - Enrichment

Gaseous phase rate = 194.6 cuft./min

Col. Diameter = 12" - 1" Intalox Saddles

Stage Length = 18" = 1.5 ft.

Number of Stages = 138

Column Height = 138 (1.5) = 207 feet

Cost = 1.093 (\$63.00/ft) (207 ft) = \$14,250.

w + w 9/22/54
✓ re w 11/22/54
cpd mnc 1-5-55

Section I - Enrichment

Gaseous phase rate = 973.2 cuft/min

Column Diameter = 30" diam Bubble Cap 13" spacing

Number of Stages = 132

Column Height = $\frac{132(13)}{0.60(12)} = 238.3 \text{ ft. (use 240)}$ Cost = $1.093(\$230/\text{ft})(240 \text{ ft}) = \$60,350.$

Stripping Section

Gaseous phase rate = 1003.07 cuft/min.

Column Diameter = 30" diam Bubble Cap - 13" spacing

Number of Stages = 80.2

Column Height = $\frac{80.2(13)}{0.60(12)} = 145 \text{ feet}$ Cost = $1.093(\$230/\text{ft})(145 \text{ ft}) = \$36,450.$

Exchange Column Summary

	Stripping Section	Sect I	Sect II	Sect III	Sect IV
N (Number of Stages)	80.2	132	138	250	223.3
Gas Flow Rate (cuft/min @ 30°C)	1003.07	973.2	194.6	35.02	2.900
Type Column	Bubble Cap	Bubble Cap	Packed	Packed	Packed
Size and Type of Packing	—	—	1" Intalox	1/2" Intalox	1/4" Raschig
Plate Spacing	13"	13"	—	—	—
Column Height (ft.)	145	240	207	187 1/2	134
Column Diameter (inches)	30	30	12	6	2 1/2
Column Cost (\$)	36,450	60,350	14,250	8,610	4,030

Total Cost Exchange Section - \$123,690

Total Cost Exchange Sect Columns (10% Insulation added) - \$136,060

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 ✓ REW - 11-22-54
 cpl Bmk 1-5-55

Flow Rates Product Type Refluxers

Refluxer I

$$\text{Aqueous flow rate} = 16.280 - 3.255 = 13.025 \text{ gal/min}$$

$$\text{Gaseous flow rate} = 973.20 - 194.62 = 778.58 \text{ cuft/min}$$

Refluxer II

$$\text{Aqueous flow rate} = 3.255 - 0.586 = 2.669 \text{ gal/min}$$

$$\text{Gaseous flow rate} = 194.62 - 35.02 = 159.60 \text{ cuft/min}$$

Refluxer III

$$\text{Aqueous flow rate} = 0.5860 - 0.0488 = 0.5372 \text{ gal/min}$$

$$\text{Gaseous flow rate} = 35.02 - 2.90 = 32.12 \text{ cuft/min}$$

Refluxer IV

$$\text{Aqueous flow rate} = 0.0488 \text{ gal/min}$$

$$\text{Gaseous flow rate} = \sim 2.90 \text{ cuft/min}$$

Data on Flow Rates from ORNL-CF-55-1-20 to determine size factors:

Aqueous flow Rate (gal./min)	Cost (\$)	Size and Type Col.
4.09	13,560	20" B.C.
1.64	8,520	14" B.C.
0.35	3,400	10" Packed

Exchange Sect 3 - Aqueous flow = 0.35 gal/min

Gaseous flow = 21.21 cuft/min

Refluxer Sect 3 - Aqueous flow = 0.35 gal/min

Gaseous flow = 21.21 + ~ 0.02 = 21.23 cuft/min

Column Diameter Sect 3 = 5" Diameter ; Refluxer = 10" Diameter

Therefore for packed columns Take Col diameter twice as large
for refluxer as for exchange column with same flowrate.

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To determine size and Cost of Product Type Refluxers

Refluxer IV

Gas rate = 2.90 cuft/min.

Column Diameter = $2\frac{1}{2}$ "

Double Diameter = $2\frac{1}{2}(2) = 5"$

Stage height = $7.5" = 0.625$ ft

Column Height = $0.625(43) = 27$ feet Packed

Cost of 30 feet of 5" Column = $1.093(30)(\$37.50) = \$1230.$
each

Refluxer III

Gas Rate = 32.52 cuft/min.

Column Diameter = 6"

Double Diameter = $6(2) = 12"$

Stage Height = $18" = 1.5$ ft.

Column Height = $1.5(43) = 65$ feet Packed

Cost of 68 feet Column = $1.093(68)(\$63.00) = \$4680.$ each

Refluxer I

For Refluxer I in original estimate (ORNL-CF-55-1-20)

Liquid Rate = 4.09 gal/min

For Refluxer I this estimate

Liquid Rate = 13.025 gal/min

$$\text{Size Ratio} = \frac{13.025}{4.09} = 3.1846$$

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Pounds/hr. other est. = 1475

Pounds/hr. this est. = $1475 (3.1846) = 4697$

Assuming 18" plate spacing (Sheet 49-original Est.)

$$G = 922.5 \text{ lbs/hr/sq.ft.}$$

$$\text{Then required area} = \frac{4697}{922.5} = 5.1 \text{ sq.ft.}$$

$$V^2 = \frac{5.1}{3.14} = 1.624 \text{ sq.ft.}$$

$$V = \sqrt{1.624} = 1.275 \text{ ft}$$

$$\text{Diameter} = 2(1.275) = 2.55 \text{ ft inside} \approx 30" \text{ pipe}$$

$$\text{Column Length} = 30(1.5) + \frac{13(1.5)}{0.6} = 77.5 \text{ feet}$$

$$\text{Cost} = 1.093(78)(\$235.00) = \$20,035 \text{ each.}$$

Refluxer II

$$\text{Size Ratio (figured as above)} = 0.6526$$

$$\text{Pounds per hour this est. } 0.6526(1475) = 962.6$$

Assuming 16" plate spacing (see Sheet 49-Original Est.)

$$G = 749 \text{ lbs/hr/sq.ft.}$$

$$\frac{962.6}{749} = 1.285 \text{ ft}^2 \text{ required} = 18" \text{ pipe}$$

$$\text{Column Length} = 30(1.333) + \frac{13(1.333)}{0.60} = 70 \text{ feet}$$

$$\text{Cost} = 1.093(70)(\$150.00) = \$11,480 \text{ each}$$

W.T.W 9-23-54
 ✓ R.R.W 11-22-54
 Cpd B.B.K 1-5-55

Summary Product Type Reflux Columns

	Column <u>I</u>	Column <u>II</u>	Column <u>III</u>	Column <u>IV</u>
Type Column	B. Cap	B. Cap	Packed	Packed
Diameter of Column	30"	18"	12"	5"
Height of Column	78'	70'	68'	30'
Cost (in duplicate)	\$40,070	\$22,960	\$9,360	\$2,460

Cost Four Refluxer in duplicate = \$74,850

Total Cost Four Refluxers (Insulation Added) = \$82,335

Determination of Product Type Reflux Auxiliary Equip Cost

Aqueous Flow in largest Product type Reflux in
ORNL-CF-55-1-20 = 4.09 gram/min.

Ratio of Aqueous flows this estimate to above:

$$\text{Refluxer I} = \frac{13.025}{4.09} = 3.1846$$

$$\text{Refluxer II} = \frac{2.669}{4.09} = 0.65257$$

$$\text{Refluxer III} = \frac{0.5372}{4.09} = 0.13134$$

$$\text{Refluxer IV} = \frac{0.0488}{4.09} = 0.011932$$

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cpd BBK 1-5-55

Cost of Auxiliary Equipment to largest Product Type
Refluxer ORNL-CE-55-1-20:

P-45	-	\$ 580
E-151	-	2840
T-91	-	43280
T-94	-	20680
P-51	-	3110
F-131	-	34320
P-52	-	720
T-95	-	6000
P-53	-	1160
Total		\$112,690

Using 0.6 factor:*

Aux. Equip Cost Refluxer I

$$\$112,690 (3.1846)^{0.6} = 112,690 (2.0037) = \$225,797$$

Aux. Equip. Cost Refluxer II

$$\$112,690 (0.65257)^{0.6} = 112,690 (0.77406) = \$87,229$$

Auxiliary Equip. Cost Refluxer III

$$\$112,690 (0.13134)^{0.6} = 112,690 (0.29583) = \$33,337$$

Auxiliary Equipment Cost Refluxer IV

$$\$112,690 (0.011932)^{0.6} = 112,690 (0.07015) = \$7,905$$

Total Auxiliary Equipment Cost \$354,268

* Williams R., "Six Tenths Factor Aids in Approximating Costs",
Chem Engr, 54, 124-5, Dec., 1947.

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 ✓ RRW-11-22-54
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Determination of Cost of Misc. Equip including Waste End Reflux

Cost of All Equip. associated with Waste end Reflux
in ORNL-CF-55-1-20:

C-1E-2, C-3	\$ 26,560
E-157, E-158	6,890
E-155	200
P-21	800
P-22	1,860
P-39	335
P-40	360
P-41	720
P-31	2,400
Total	\$ 40,125

Cost of other misc Equip upon which 0.6 factor may
be used:

Demineralizer	\$ 5,470
T-100	3,410
Slaker	30,000
P-61	3,110
Belt Conveyor	2,500
Bucket Conveyor	1,500
T-102	10,100
P-62	3,110
Drum Dryer	32,450
Calciner	65,000
C-14	985
T-101	635
P-65	335
P-60	350
F-134	50
E-154	3,500
Total	\$ 162,505

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✓ RRV-11-22-54
cpd MMK 1-6-55

Total of Items = \$202,630

$$\text{Size Ratio} = \frac{\text{Mass Flow this Est}}{\text{Mass Flow First Est}} = \frac{1108.93}{414.325} = 2.676$$

Cost of Misc Equip including Waste End Reflux:

$$\$202,630 (2.676)^{0.6} = \$365,747$$

Cost of Gas Pumps

Duty	Cu ft/min	No	Head ft	H.P.	Comp.	Cost
To Strip Cols	1014	2	10	60	\$5800(2)	\$11,600
To C-I's	984	2	10	60	"	11,600
To C-II's	197	2	10	13	\$2400(2)	4,800
To C-III's	35	2	10	4	\$1475(2)	2,950
To C-IV's	2.9	2	10	1	\$740(2)	1,480

Total \$32,430

Cost of Liquid Pumps

Duty	gal/min	Head ft	No.	RPM	Cost Each	Cost
To Str. C + CI's	25	150	3	3500	\$420	\$1260
To P. Reflux I	15	100	1	1750	580	580
to C II	5	150	2	3500	420	840
to P. Reflux II	5	100	1	1750	580	580
to C-III's	1	150	2	3500	420	840
To P. Reflux III	.1	100	1	1750	580	580
to C-IV's	0.1	150	2	3500	420	840
to P. Reflux IV	0.1	50	1	1750	330	330

Total \$5850

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✓ RW-11-22-54
Cpd BRK-1-6-55

Cost of Dump Tanks

Duty	Capacity Calc.	Capacity gal	No	Cost Each	Cost
For Strip Col	72.5 (4.51) (7.48)	~ 2500	2	\$1530	\$3060
For Col. I	120 (4.51) (7.48)	4000	2	1920	3940
For Col. II	104 (4.51) (7.48)	600	2	700	1400
For Col. III	94 (4.51) (7.48)	150	2	220	440
For Col. IV	63 (4.51) (7.48)	20	2	110	220
Total					\$9060

Cost of Product Pump (same as original) = \$300
 Cost of Product Heat Exchanger (" " ") 50
 Total \$350

Summary of Cost of Exchange Auxiliary Equip.

Gas Pumps	\$32,430
Liquid Pumps	5,850
Dump Tanks	9,060
Total	\$47,340

Equipment Cost Summary

Exchange Columns	\$136,060
Exchange Auxiliary Equip	47,340
Product Reflux Columns	82,335
Product Reflux Aux. Equip	354,268
Wast End Reflux and Misc.	365,747
Product Pump and Heat Exchg.	350
Total	986,100

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 cpl BBK 1-6-55

APPENDIX C - RAW MATERIALS AND MANPOWER REQUIREMENTS

RAW MATERIALS COSTS

1. NH_3 Feed:

$$\frac{34(17)(60)(24)}{453.6} = 1835 \text{ lbs/day}$$

$$\frac{1835 (\$103.50)}{2000} =$$

$\$94.96/\text{day}$

2. CaCO_3 :

$$\text{Size Factor} = 2.676$$

$$1.16 \text{ Tons} (2.676) (\$4.30) =$$

$\$13.35/\text{day}$

3. Fuel Oil (Calciner):

$$\$42.30 (2.676) =$$

$\$113.19/\text{day}$

4. Steam:

$$\$98.10 (2.676) =$$

$\$262.52/\text{day}$

5. Process Water:

$$\$0.72 (2.676) =$$

$\$1.93/\text{day}$

6. Cooling water:

$$\$41.81 (2.676) =$$

$\$111.88/\text{day}$

Total

$\$597.83/\text{day}$

$\$218,208/\text{yr.}$

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CK BBK 1-6-55

Man Power Costs

Operators per shift	12
Supervisors per shift	1
Total shift workers per shift	13
Man hours per day by Shift workers	312
" " " " by Overall Supervisor (1)	8
" " " " Lab Personnel (5)	40
Total man hours per day	360
Total man hours per year	131,400
Total cost per year at \$3/hr.	\$394,200

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 ✓ RRW - 11-23-54
 CLE BBRK - 1-6-55

APPENDIX D - BASES FOR ESTIMATING COST

The cost of producing the nitrogen 15 isotope may be divided into two types of costs, as follows:

1. Fixed Costs. These include

① investment costs such as depreciation, interest on invested capital, and taxes, and ② Overhead.

2. Variable Costs. These include raw materials, labor, utilities, maintenance, supplies, packaging, storage and shortages.

The method used to determine these costs is outlined in the following paragraphs.

Total Plant Investment

The total plant investment is the sum of a series of costs, estimated as follows:

A. Installed Equipment

1. Exchange and Product Reflux Columns

The diameter and height of the exchange columns were calculated on the bases of

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information on the number of stages and inter stage flows obtained from the ideal cascade curve, Figure A-1, and Appendix B. The sizes of the product reflux columns were calculated on the basis of these flows. The cost of this installed equipment was then obtained from cost data by C.H. Chilton* with the prices adjusted to the 1953 level.

2. Remainder of the Equipment

The cost of the remainder of the equipment was scaled up directly from ORNL-CF-55-1-20 using the 0.6 factor**

B. Process Piping (0.60 times installed equipment cost "A"). C.H. Chilton* recommends a factor of 30-60% for fluids processing plants. Because of the extreme importance of having a leak-tight system, the maximum factor was chosen.

* Chilton, Cecil H., "Cost Data Correlated", Chem. Engr., June, 1949.

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** Williams, R., "Six Tenths Factor Aids in Approximating Costs", Chem Engr., 54, 124-5, Dec, 1947.

C. Instrumentation (0.14 times installed equipment costs "A"). A factor ranging from 2 to 15 % is recommended by Chilton*. A figure close to the maximum was chosen here because of the close flow control required.

D. Process Buildings (0.30 times installed equipment costs "A"). Chilton* recommends a factor of 20 to 60 percent for mixed indoor-outdoor construction. Since the columns, which constitute a major portion of the equipment space-wise, can be installed outdoors, a factor of 30% was chosen.

E. Laboratory Furniture and Equipment (0.03 times installed equipment cost "A"). This factor was based on local experience.

F. Service Facilities (0.30 times installed equipment costs "A"). For complete facilities at a new site Chilton* recommends

* Chilton, Cecil H, Ibid.

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a factor of 25-100%. Since the utilities demands are not unusually large, the relatively low factor of 0.30 was chosen.

G. Total Physical Plant This is the sum of the costs given in Items "A", "B", "C", "D", "E", and "F".

H. Engineering (0.4 times the total physical plant "G"). According to Chilton* this factor will vary from 35 to 50% in cases where the engineering is complex and a high labor to materials ratio exists.

I. Site Development (0.15 times installed equipment cost "A"). H.E. Schweyer** gives a range of from 0.09 to 0.28 for this factor.

J. Pre operational Costs (0.40 times the total physical plant "G"). This cost includes leak testing, equipment shake down, operator training, and other start up costs incurred prior to routine operation.

K. Contingency (0.25 times the total physical plant "G"). Chilton* recommends a factor of 20 to 30 % of the total.

* Chilton, Cecil H, Ibid.

** Schweyer, H.E., "Cost Estimation of Process Operations", Chem and Engr. News, Vol. 31, No 32, Aug 10, 1953.

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physical cost for an average plant which is subject to change.

- L. Working Capital This item includes the cost of materials inventories and in-process materials plus the cost of one months operation.
- M. Total Plant Investment This is the sum of the cost of the total physical plant, engineering costs, site development, preoperational cost, contingency, and working capital ("G" + "H" + "I" + "J" + "K" + "L").

N. Fixed Costs

(1) Investment Costs

(a) Depreciation. This item is calculated to be 15% of the total plant investment minus the working capital $[0.15("M" - "L")]$. This is the standard rate of depreciation used for A.E.C. Installations.

(b) Interest Charge on Total Fixed Capital

This is figured at one percent per year on the total plant investment minus the working capital $[0.01("M" - "L")]$.

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(C) Interest Charge on Working Capital

This is figured at one percent per year of ~~the~~ working capital ($0.01 \times$ ~~the~~ "L").

(d) Payment in Lieu of Taxes This

item is calculated to be one percent per year of the total plant investment minus the working capital $[0.01 ("M" - "L")]$.

(2) Overhead This is estimated to be equal to the sum of the following:

(a) 70% of the cost of labor and supervision.

(b) 100% of the cost of maintenance and supplies.

O. Variable Costs

(1) Raw Materials Consumed per Year. The detailed calculations of the Raw Materials required are given in Appendix "C".

(2) Direct Labor and Supervision. The number of men required was estimated after reviewing the man-power estimates for three other plants and considering these in conjunction with local experience. A charge of \$3.00 per man hour was assumed. For details see Appendix "C".

- (3) Utilities (0.06 times the total physical plant "G"). This item includes all of the electricity, water for domestic use only, and steam for general heating (buildings, etc.) only. The process water, cooling water, and steam used for process heating are included under raw materials.
- (4) Maintenance (0.05 times the total physical plant "G"). This factor was based on local experience.
- (5) Supplies (0.005 times the total physical plant "G"). This factor was likewise based on local experience.
- (6) Packaging, Storage, Shortage, etc. (0.05 times the sum of the cost of raw materials and the cost of labor and supervision.)

Cost Per Pound

This is the sum of the annual fixed costs plus the annual variable costs, divided by 365 days and the daily production rate.

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Scale-up Method used for Determining the
Cost per Pound at a Production Rate
of 50 pounds per Day.

1. Installed Equipment ("A").

The method of calculating the cost of the installed equipment for the scaled-up plant is given in Appendix E.

2. Total Plant Investment ("M")

The total plant investment was calculated from the cost of the installed equipment in the same manner as described on the previous pages for the one pound per day plant.

3. Operating Costs ("N" + "O")

The fixed costs ("N") were calculated in the same manner as described for the one pound per day plant. The variable costs ("O") were also calculated as described for the one pound per day plant with the following exceptions:

(a) Raw Materials The raw materials consumption was assumed to be exactly 50 times that for the one pound per day production rate.

BMR 1-6-55

(b) Labor and Supervision The cost of labor and supervision for the one pound per day plant (Case I - ORNL-CF-55-1-20) was scaled-up using the 0.6 factor*.

The cost per pound was then calculated as described for the one pound per day plant.

* Williams, R., Ibid.

APPENDIX E - COST CALCULATION

DETAILS

In Process Materials and Material

Inventory Calculations

Volume of exchange columns = sum of
volumes of dump tanks = $7270(2) = 14,540$ gals.

In original estimate, vol exchange columns
(ORNL-CF-55-1-20) = $1580 + (1090 + 362 + 115)2 =$
4715 gallons.

Determination of scale Ratio = $\frac{14,540}{4,715} = 3.084$

Ratio in remainder of plant = 2.676

Assuming 50% holdup is in exchange columns,

Average ratio = $\frac{3.084 + 2.676}{2} = 2.88.$

Item	In Process lbs	Additional Inventory	Total lbs.	Price	Cost
NH ₃	$2177(2.88) =$ 6270	$1835(7) =$ 12,845	~19,000	\$103/ton	\$1983
CaCO ₃	$6 \times 2.88 =$ ~17 tons	$3.1(30 \text{ days}) =$ 93 tons	110 tons	\$43/ton	\$473
Fuel Oil	—	2 weeks 15,000 gals		\$0.10/gal	\$1500

Total \$2956
or approx \$3000

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CPL mme 1-9-55

Working Capital (one pound per day plant)

1	N+O - Nic per year	\$2,155,877
	" " per month	179,656
	Material Inventory	3,000
	Approximate L	182,656
2	Approximate Nic = 0.01L	1827
	Approximate N+O = ① + ② (per year)	2,157,704
3	" " per month	179,809
4	Material Inventory	3,000
	L = ③ + ④	182,809

The following estimates have been made:

1. One pound per day plant assuming perfect (No loss) reflux (ORNL-CF-55-1-20).
2. One pound per day plant assuming 0.001 loss at each product refluxer (This report).
3. Fifty pounds per day plant assuming perfect (No loss) reflux (ORNL-CF-55-1-20)

Assuming the same scale-up factors to be applicable, individual items in the cost estimate for a 50 pound per day plant

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✓ R R W - 11-26-54

Cpl M M K - 1-9-55

assuming losses of 0.001 at each product
refluxer may be calculated from the
ratio:

$$\text{Cost 50 lb/day plant (0.001 losses)} = \frac{\text{Cost 50 lb/day plant (no losses)}}{\text{Cost 1 lb/day plant (no losses)}} \times \text{Cost 1 lb/day plant (0.001 losses)}$$

$$\text{Installed Equipment Cost} = \frac{7,377,095}{624,560} \times 986,100 = \$11,647,488$$

$$\text{Raw Materials} = \frac{3,939,800}{78,796} \times 218,208 = \$10,910,400$$

$$\text{Labor and Supervision} = \frac{3,587,220}{341,640} \times 394,200 = \$4,139,100$$

WORKING CAPITAL Cost Estimation

1	N+O - N _{ic} (per year)	\$33,309,312
2	" " (per month)	2,775,776
3	In process Materials and Inventory (50)(3000)	150,000
4	Approximate L (2)+(3)	2,925,776
5	Approx N _{ic} = 0.01 L	29,258
6	Approx N+O = (1)+(5) per year	33,338,570
7	" " per month	2,778,214
8	Inventory (3)	150,000
	L (7)+(8)	2,928,214

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✓ RW - 11-26-54

CPD BSK - 1-9-55