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TNT PURIFICATION STUDIES. TASK II. COMPARATIVE COST STUDY OF PU--ETC(U)

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TNT PURIFICATION STUDIES - TASK II - COMPARATIVE COST STUDY OF PURIFICATION METHODS

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US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
FIRE CONTROL AND SMALL CALIBER
WEAPON SYSTEMS LABORATORY
DOVER, NEW JERSEY

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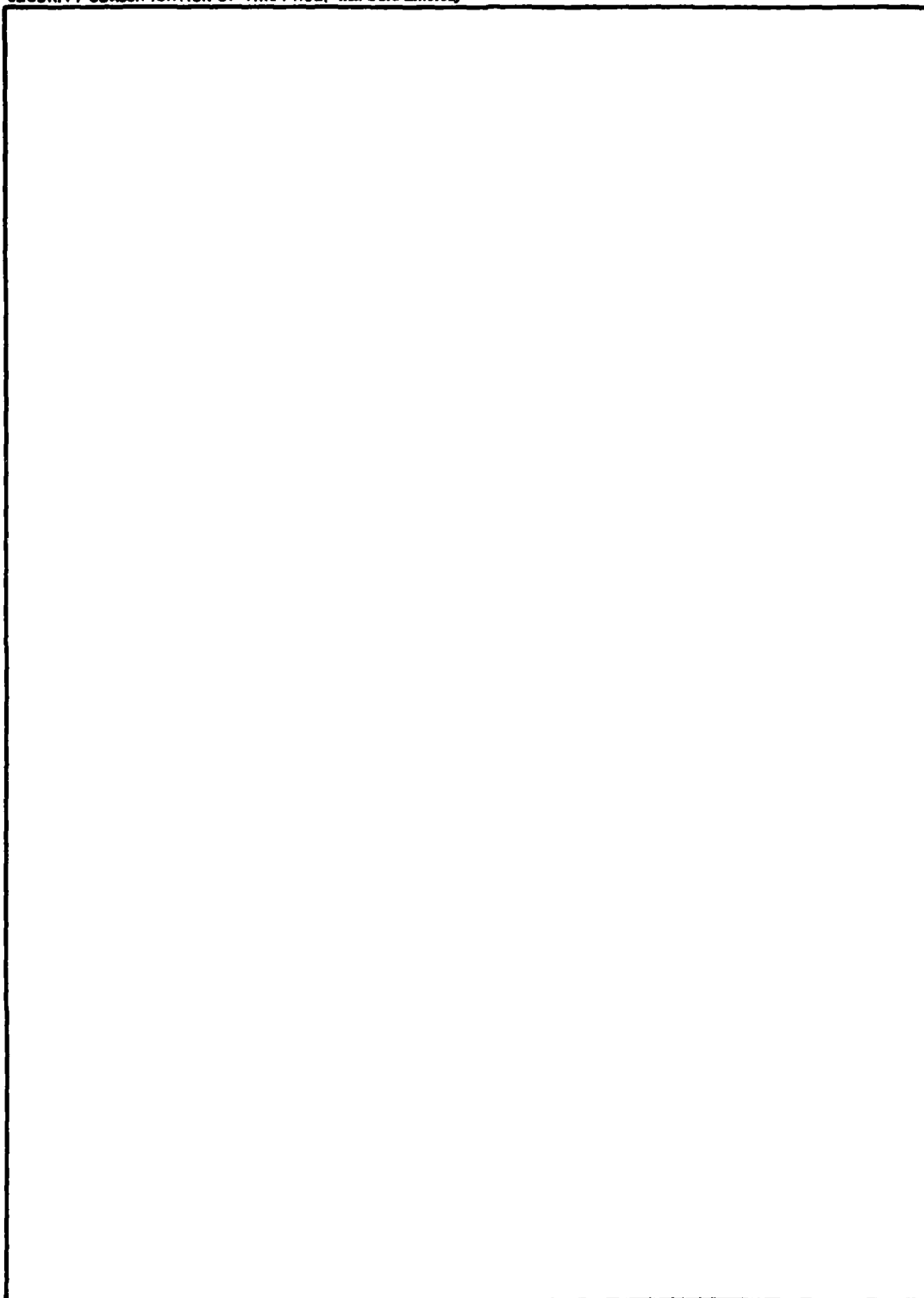
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INTRODUCTION

Trinitrotoluene (TNT) must be purified before it can be of value as an explosive. Crude TNT is composed of Δ -TNT and unsymmetrical TNT isomers. For years the Sellite process (where TNT is contacted with sodium sulfite) has been employed for purifying TNT. The purification process removes the unsymmetrical TNT isomers by converting them into water soluble dinitrotoluene sulfonates. The aqueous wash solution from the Sellite process is commonly referred to as red water and also contains complexed Δ -TNT and various oxidation products.

The customary red water treatment approach is the incineration of a concentrated solution of the red water in a rotary kiln to produce an ash. The ash creates several problems. When landfilled, the ash will produce a leachate which may contain nitroaromatics. Although the ash has been landfilled with plastic liners, a leachate still may be produced and create a problem with time. Red water was once sold to paper mills for its sodium and sulfur values but the Environmental Protection Agency has now classed red water as a toxic material. Because of this ruling, paper mills are reluctant to accept red water due to severe transportation and plant operational restrictions.

Efforts have been directed toward developing a pollution free TNT purification and waste disposal process. Candidates were: (1) Sellite process with sulfite recovery via the Sonoco process, (2) magnesium sulfite purification and disposal process, (3) the nitric acid recrystallization process and (4), ammonium sulfite purification. The first three processes were evaluated and reported in June 1979 under, "Task I - Comparative Cost Study of Purification Methods", Production Engineering Report 556.

The ammonium sulfite purification process was evaluated in and reported in the March 1976 PE-503 report entitled, "Ammonium Sulfite Purification of TNT". Ammonium sulfite is capable of purifying TNT under conditions used in the cold batch TNT purification process. Under continuous TNT purification conditions where TNT is in the molten state, TNT of acceptable purity was not obtained. Impurities which were aminodinitrotoluenes imparted a bright yellow color to the TNT and reduced its freezing temperature. The purpose of this cost study is to determine if the recovery process of ammonium sulfite wastes is economically attractive to warrant further purification studies.

CONFIGURATIONS AND DETAILED DESCRIPTION OF THE PURIFICATION SYSTEM

After the nitration of toluene is complete, it is necessary to purify the crude TNT by removing the unsymmetrical isomers and various oxidation products. The purification approach contained in this report is the ammonium sulfite process with partial recovery of purification chemicals.

Ammonium Sulfite Purification System

The ammonium sulfite approach employs an aqueous solution of ammonium sulfite to purify the TNT. Nucleophilic attack by the sulfite ion results in replacement of the meta nitro group on the unsymmetrical TNT isomers which produce a water soluble dinitrotoluene sulfonate compound. The resulting solution has a red coloration similar to that of Sellite red water.

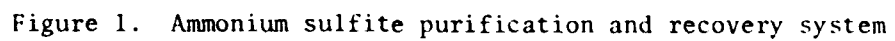
Ammonium sulfite has been shown to be capable of purifying TNT under TNT batch processing conditions. It is not capable of purifying TNT in the continuous TNT process because the higher purification temperature used to maintain TNT in a molten state produce undesirable reaction products. However, for purposes of calculations and comparisons with other TNT purification candidates, purification of TNT was assumed feasible in the continuous process.

Figure 1 shows a flow chart of the entire purification and recovery system detailing utility needs as well as the equipment and chemical requirements.

Figure 2 shows the purification process material balance. Weak nitric acid is added to acid washer No. 1 for passivation of the stainless steel and fresh water is added to acid washer No. 2 with the wastes of the combination of these two ingredients being sent to the nitration process for use. TNT isomer removal takes place in the three Sellite washers with the addition of the aqueous ammonium sulfite solution. The concentration of the ammonium sulfite solution is at 18.8 percent solids coming from the recovery process and is combined with the post Sellite wash water (used to remove traces of red water in purified TNT) in a mix tank to produce a 15 percent solution.

The ammonium sulfite solution flows counter-current to the nitrobodies and the resulting red water leaving Sellite washer No. 1 is sent to the chemical recovery unit for the recovery of sulfur.

Figure 3 is a diagram of the recovery process. This flow diagram depicts the pumps, tanks and all other equipment necessary for the recovery of sulfur from ammonium sulfite red water. The 20 percent solids red water wastes flows from the purification process to a storage tank which feeds the



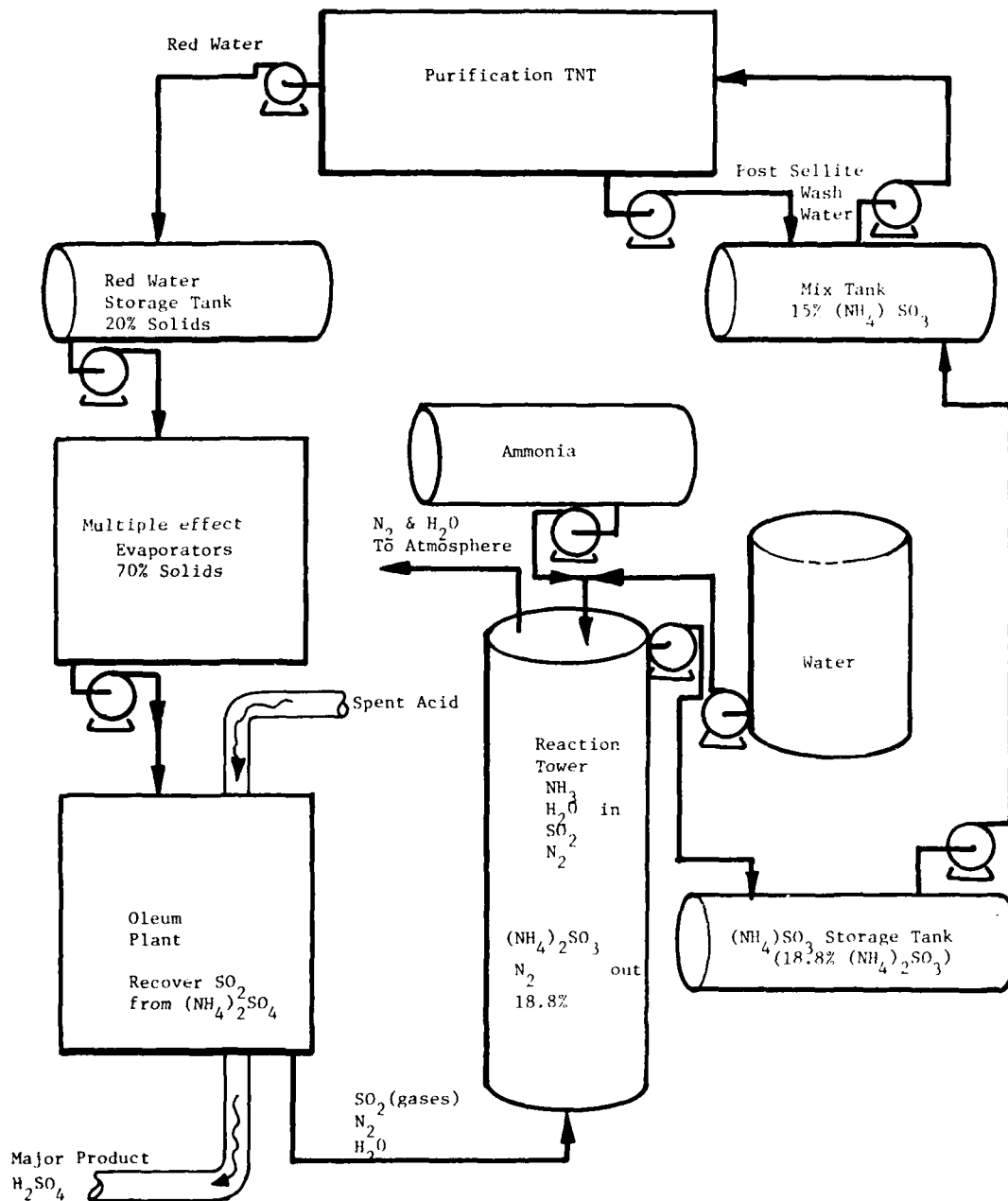


Figure 3. Ammonium sulfite recovery process

multiple effect evaporators. The red water will be concentrated to 70 percent solids and pumped to the oleum plant furnace. Here the ammonium sulfate is thermally degraded to nitrogen, sulfur dioxide and water. The sulfur dioxide is recovered and sent to a reaction tower where it is chemically combined with an aqueous solution of ammonia to form a 18.8 percent ammonium sulfite solution.

Figure 4 shows the energy efficiency of the system. It is assumed that an outside source of energy is required to concentrate the red water to 70 percent solids before it enters the oleum plant furnace.

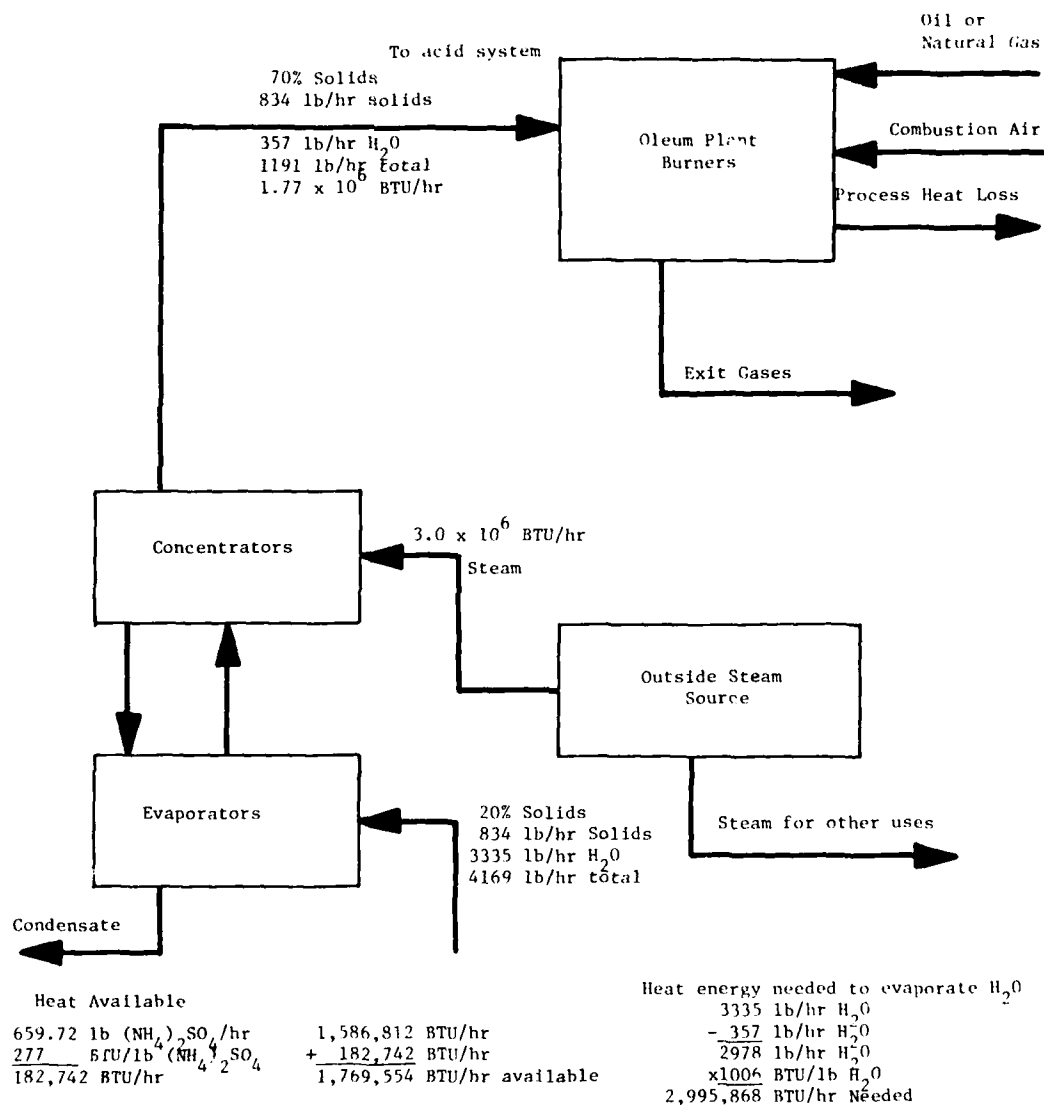


Figure 4. Energy efficiency in the ammonium sulfite purification system

ECONOMIC EVALUATION OF THE PROCESS

Capital and operating costs have been determined for the ammonium sulfite purification and recovery process and compared with the Sellite process in this evaluation. In order to achieve a suitable margin for comparison, assumptions have been developed as guidelines for the calculations and these are presented in Appendix A.

Ammonium Sulfite Process

Capital Costs

The capital costs for the ammonium sulfite process with partial chemical recovery are shown in Table 1 and detailed in Appendix B. The capital cost of \$1,021,086 for the continuous ammonium sulfite purification section has not been included in the implemented cost for RAAP since all purification equipment has already been installed. However, this cost should be included as a capital cost for any other plant which does not have such installed facilities. The capital cost of the continuous purification process includes dynamic separators, all necessary support equipment, buildings, piping, instrumentation and electrical supplies. The total capital cost of the recovery process is \$5,103,720. RAAP's implemented cost is \$3,940,022 for the total system. The difference is due to the oleum plant facilities which are presently at RAAP. The actual cost of an oleum plant is \$14,191,439, but this report reflects only the percentage of the plant needed for recovering the sulfur from the red water solids. This amounts to 8.20 percent of the oleum plant capacity and costs. Additional major equipment required includes evaporators, tanks, pumps, lines, an ammonia reaction tower, insulation and all equipment for the recovery unit. The total costs include buildings and site preparation both at the TNT plant and at the oleum plant, an electrical substation, and all needed instrumentation.

Overhead capital costs have been adopted for all systems or parts of systems which will be installed at the site. These are: 8.8 percent for Corps. of Engineers, 10 percent for contingency, 10 percent for construction fee, and 25 percent for detailed and process engineering.

Operating Costs

Table 1 also shows a summary of the individual operating costs for the continuous purification process and the recovery system. This table contains all operating costs given in dollars per pound of finished TNT. No additional labor is required for the purification system; however, the recovery unit requires a minimum of 10 additional workers on a 3-8-7 shift arrangement.

Table 1
Summary of Ammonium Sulfite Purification Cost

<u>Capital Cost</u>	<u>Continuous Purification</u>	<u>Recovery</u>	<u>Total</u>
Facility Cost	\$1,021,086	\$5,103,720	\$6,124,806
Implementation Cost at RAAP	-----	3,940,022	3,940,022
<u>Operating Cost (\$/lb finished TNT)</u>			
Labor	-----	0.00622689	0.00622689
Electricity	0.0005466	0.00036697	0.00091357
Steam	0.0036149	0.0011568	0.0047717
Cooling Water	0.0004193	0.00001800	0.0004373
Compressed Air	-----	0.00001119	0.00001119
Chemicals	0.0181848	*-0.0012652	0.016920
Residue Loss	0.0046061	-----	0.0046061
Maintenance	0.0014587	0.0072910	0.0087497
Depreciation	0.0029174	0.0145821	0.0174995
Total	0.0317478	0.0283879	0.0601355

* - Credit

The cost of electrical power includes the cost for operation of fans, stirrers, pumps and the hydraulic system. The cost of steam is the cost of heating the water used in the acid washer, the post Sellite washer and the make-up sulfite solution. It also includes the steam required in the recovery system for concentrating the red water to 70 percent solids. No cost is included for the steam heating of vessels and interconnecting lines, since this applies only to startup. The heat evolved by the exothermic reaction of crude TNT and ammonium sulfite is sufficient to maintain the purification vessels at a constant temperature. A credit is taken for the energy evolved in the recovery process for the incineration of both the nitro bodies and ammonium sulfate found in the red water. The cost given for the water includes the water used to cool the purification vessels as well as all the water used in the recovery process. The compressed air cost is the cost of operating the compressor in the recovery system.

The cost of the chemicals is the cost of producing 580 pounds per hour of ammonium sulfite from ammonia, sulfur dioxide, and water. Additionally the cost was determined for purchasing the ammonium sulfite from a vendor rather than manufacturing at RAAP. It requires 0.1311 pounds of pure ammonium sulfite to purify one pound of TNT. At \$0.38 per pound of commercially supplied ammonium sulfite, it would cost 4.9822 cents per pound of finished TNT. It would cost 1.8185 cents per pound of finished TNT to manufacture ammonium sulfite.

A credit is claimed in the recovery section for the sulfur in the red water. This cost estimate assumes 100 percent recovery of sulfur. The ammonia and the cost of operation for the oleum plant are considered as costs. It is assumed that it will cost the same to recover sulfur from ammonium sulfate as from sulfuric acid.

The residue loss figure is the cost of losing one percent of the α -TNT in the purification process.

The maintenance cost is taken as five percent of the capital investment in both the purification and recovery systems. The depreciation is taken as a 10-year straight line depreciation on the capital costs.

The total operating cost for the ammonium sulfite purification and recovery operations is calculated to be 6.0136 cents per pound of finished TNT.

Sellite Process

Capital Costs

Table 2 is a summary of the costs taken from the Sellite section of a cost estimation report entitled, "TNT Purification Studies, Task I-Comparative Cost Study of Purification Methods", by J. R. Spencer, June 1979. Each of the capital costs were escalated to current prices for a

Table 2

Summary of Sellite Purification Cost

<u>Capital Costs</u>	<u>Continuous Purification</u>	<u>Recovery</u>	<u>Total</u>
Item			
Facility Cost	\$1,021,086	\$5,344,944	\$6,366,030
Implementation Cost at RAAP		5,344,944	5,344,944
<u>Operating Costs</u>	<u>\$/lb. TNT</u>	<u>\$/lb. TNT</u>	<u>\$/lb. TNT</u>
Labor	-----	0.010642	0.010642
Electricity	0.000550	0.001688	0.002238
Steam	0.001019	0.000915	0.001934
Cooling Water	0.000422	0.002628	0.003050
Compressed Air	-----	0.000047	0.000047
Fuel	-----	0.005062	0.005062
Chemicals	0.015952	*0.015952	0.000000
Residue Loss	0.006980	-----	0.006980
Maintenance	0.001459	0.007636	0.009095
Depreciation	0.002918	0.015276	0.018194
Total with Recovery Credit	0.029300	0.027942	0.057242

* Credit due to recovered chemicals

direct comparison between the two systems. RAAP's implemented cost is \$5,344,944.

Operating Costs

The operating costs for the Sellite system are also given in summary on Table 2. These costs likewise have been escalated to reflect current prices. The operating cost for the Sellite system is 5.7242 cents per pound of finished TNT.

CONCLUSIONS

The estimated comparative investments for the two purification processes are shown below in thousands of dollars. Both the total facility costs and the implemented costs at RAAP are given. The estimated operating costs for the processes are shown in dollars per pound of finished TNT:

	Ammonium Sulfite	Sellite
Total Facility Costs (thousands)	\$6,125	\$6,366
RAAP's Implemented Costs (thousands)	\$3,940	\$5,345
Operating Cost (\$/lb TNT)	0.060136	0.057242

The total facility costs which include the oleum plant for the ammonium sulfite process are very similar as indicated in the table. The major difference between the two implemented costs is the cost of the oleum plant which already exists at RAAP.

There is an indicated savings of \$0.002894 per pound of TNT for the Sellite purification system as compared to the ammonium sulfite system. This amounts to a difference of about \$101,000 between the two systems on a yearly production of 35,000,000 pounds of TNT per line.

This cost study gives credit for a 100 percent recovery and reuse of the chemicals in the Sellite system, but only the sulfur in the ammonium sulfite system. The actual recovery efficiencies could not be determined but will be somewhat less than 100 percent. An energy credit is given for both systems because of the burning of the nitro bodies in the Sellite system and the burning of both the nitro bodies and the ammonium sulfate salt in the ammonium system.

This cost study assumes that the two purification systems will operate similarly; however, laboratory studies to date indicate that the continuous ammonium sulfite process is not feasible in the present form. It also assumes that the sulfur can be recovered from the chemicals by processing the red water through the oleum plant, but this process also has not been proven commercially or demonstrated on a laboratory scale. The Sellite purification system is presently used for TNT manufacture. Recovery of Sellite from the red water is being pursued using Sonoco Products Company (Hartsville, South Carolina) technology.

RECOMMENDATIONS

A review of the capital and operating cost and the process chemistry of TNT purification and waste recovery indicate that the ammonium sulfite process does not offer an advantage over the Sellite process and additional efforts in the area do not appear warranted.

APPENDIX A
ASSUMPTIONS FOR THE COMPARATIVE COST STUDY

This is a hypothetical cost study and is based on the following assumptions:

1. The continuous ammonium sulfite process has not been proven in the laboratory or in full-scale operations; therefore, this cost study is considered hypothetical.
2. The capital investment in the purification phase is calculated per TNT line.
3. The capital investment on the recovery phase is calculated to process wastes from two TNT lines.
4. All operating costs are based on a 50-ton per day production line and are given as dollars per pound of finished TNT.
5. Four and one-half percent loss of the crude TNT due to the unsymmetrical isomers will occur in the purification process.
6. The residue loss is assumed to be only the α -TNT lost. This amounts to 1.0 percent for the ammonium sulfite purification process.
7. The ammonium sulfite recovery system is assumed to recover 100 percent of the sulfur present in the ammonium sulfite wash water. The ammonia is lost in the system via reduction to nitrogen.
8. No material or equipment costs are included for addition of chemicals lost because of process inefficiencies.
9. No license fees are included in either the purification or the recovery costs.
10. The costs do not include utility services, safety devices, or any other requirements to meet applicable standards.
11. No nitro bodies are reclaimed from the red water.
12. The oleum plant costed in this report will process the red water from three TNT production lines. This unit is rated for 500 tons of oleum production per day. Each TNT line will produce from 150 to 170 tons per day of spent nitrating

acid and 15 tons per day of red water concentrated to 70 percent solids. The capital cost is calculated to be 8.20 percent of the total oleum plant actual cost. This is the amount of the oleum plant used for sulfur recovery from the red water.

13. The chemical recovery section of the ammonium sulfite purification system has a deficiency in energy required to concentrate the red water to 70 percent solids. This energy will be supplied from a steam source external to the recovery system.
14. The actual implementation capital cost of the ammonium sulfite purification system at RAAP is the total capital cost less the TNT purification cost and the oleum plant costs. This implementation cost is presented because RAAP and some other facilities already have the Sellite purification system and oleum plants.
15. The amount of ammonia lost in purification of the TNT is considered negligible and thus not included as a cost in the process.
16. Since all ammonia is lost in the recovery process, additional ammonia is required and priced at current levels.
17. The depreciation of this system is accepted as a 10-year straight line depreciation.
18. The maintenance of this ammonium sulfite purification system is accepted as five percent of the initial capital investment.
19. All nitrobodies leaving the TNT purification line are considered soluble in the red water and will be destroyed in the oleum plant's furnace. It is assumed that this method of destroying the nitrobodies will not damage the furnace or have any other adverse affect.
20. The capital cost of the recovery section includes an additional cost for Corps. of Engineers (8.8 percent), contingency (10 percent), construction fee (10 percent), and detailed and process engineering (25 percent).
21. No additional labor is required for the purification phase of the system. The operators required for the nitration process will also control purification.

22. The recovery section requires, at a minimum, ten operators. This number is an assumption based on anticipated requirements.
23. All operational costs are based on current prices of the involved items or goods at RAAP.
24. The purification costs are the same as those on the Sellite system since the operation and equipment are assumed to be identical.
25. The nitrobody value is assumed to be \$0.456 per pound. The current market price may be much higher.
26. The heat of vaporization for water is 2,338,391 joules per kilogram or 1006 BTU per pound.
27. No overhead or fringe benefits are included.
28. Two moles of ammonia combined with one mole of water and one mole of sulfur dioxide to form one mole of ammonium sulfite with no loss of either of the materials.
29. It is assumed that the cost of processing sulfur in the oleum plant is the same from ammonium sulfate as from spent sulfuric acid.
30. A credit is given for the energy obtained due to the incineration of the nitrobodyes and ammonium sulfate present in the red water.
31. The multiple effect evaporators priced within this report will concentrate the red water from 20 percent to 70 percent solids.
32. The electric pumps used to transport red water and ammonium sulfite will operate 35 percent of the time.
33. The capital costs are given in dollars. The operating costs are given in dollars per pound of finished TNT.
34. It is technically feasible to mix the 70 percent solid red water with the 70 percent spent acid for injection into the oleum plant furnace.
35. In the preparation of ammonium sulfite, the ammonia and water will mix readily without outside initiation.
36. The capital cost included in this report for the TNT purification section is RAAP's cost. Should this process be implemented elsewhere, there may be additional capital costs due to Corps of Engineers, contingency, construction fee and detailed and processing engineering.

37. The ammonium sulfite used for purification is a 15 percent aqueous solution. The mole ratio of TNT: $(\text{NH}_4)_2\text{SO}_3$ is 3.9:1. The weight ratio of TNT: $(\text{NH}_4)_2\text{SO}_3$ is 7.7:1.
38. The sulfur in the red water is assumed to be in the form of sulfate due to air oxidation.

APPENDIX B
COST DATA FOR THE AMMONIUM SULFITE PURIFICATION SYSTEM

1. Capital Costs¹

A. Purification

Building and Services	\$261,288
Process Equipment	498,510 ²
Process Piping	126,060
Instrumentation	64,176
Electrical Instrument, etc.	<u>71,052</u>
	\$1,021,086 ³

¹The Purification system of the ammonium sulfite process will be the same as the Sellite purification process. These figures were taken from the Sellite cost data entitled, "Task I-Comparative Cost Study of Purification Methods", dated June 1979 by J. R. Spencer and escalated to 1980 prices.

²Includes dynamic separators

³This system has been implemented at RAAP; therefore, this cost can be deducted from the total capital cost when calculating the implemented cost for the ammonium sulfite system at RAAP.

B. Recovery

Major Equipment

Oleum Plant	\$14,191,439 x 8.2%	= \$1,163,698
Evaporators		845,748
Ammonia tower		273,464
Tanks (4)		194,707
Pumps (8)		57,669
Lines		<u>48,968</u>
		\$2,584,254
Buildings and Site Preparation ¹		583,680
Electrical ²		<u>150,480</u>
		\$3,318,414
Corps of Engineers	8.8%	\$292,020
Contingency	10%	331,841
Construction fee	10%	331,841
Detailed and Process Engineering	25%	829,606
		<u>\$1,785,306</u>
	Total	<u>\$5,103,720</u>
RAAP's Implemented Cost (Total-Oleum Plant Costs)		\$3,940,022

¹Includes miscellaneous equipment, piping, insulation and painting.

²Includes instruments, wiring and substation.

2. Operating Costs

A. Purification

Electrical Power	H.P.
Yellow Water Tank Stirrer	0.25
Sulfite Washer Drive, No. 2	
Washer	1.00
Post Sellite Stirrer	0.25
Fume Recovery Fans	4.00
Weak Nitric Pump	0.15
Dissolver #1 Feeder	0.33
Dissolver #1 Mixer	0.75
pH Control Dissolver Feeder	0.33
pH Control Dissolver Mixer	<u>0.75</u>

7.81

$$\frac{7.81 \text{ Hp/hr} \times 24 \text{ hr/day} \times 0.7457 \text{ KWH/HP} \times \$0.031065/\text{KWH}}{100,000 \text{ lb TNT/day}} = \$0.00004342/\text{lb. TNT}$$

Hydraulic Motors	H.P.
#1 Acid Washer	14
#2 Acid Washer	14
#1 Sellite Washer	14
#2 Sellite Washer	2.5
#3 Sellite Washer	14
#1 Post Sellite Washer	14
#2 Post Sellite Washer	14
Yellow Water Pump	2
TNT Pump Tank	<u>2</u>

90.5

$$\frac{90.5 \text{ HP/hr} \times 24 \text{ hr/day} \times 0.7457/\text{KWH/HP} \times \$0.031065/\text{KWH}}{100,000 \text{ lb. TNT/day}} = \$0.0005031/\text{lb. TNT}$$

Subtotal \$0.0005466/lb. TNT

Steam

(all solutions used at 80°C)

Hot water requirements

Acid Washer No. 2	714 lb/hr
Sellite washer	<u>3091</u> lb/hr
	3805 lb/hr

Steam to TNT Plant cost \$3.78/1000 lb steam
Steam to TNT Plant contains 960.9 BTU per lb.
1006 BTU required per lb. of water to attain 80°C
Coal - \$43.32 per ton or \$0.02166 per lb.

3806 lb/water/hr x 24 hr/day x 1006 BTU/lb. water x \$0.00378/lb. Steam
100,000 lb. TNT/day x 960.9 BTU/lb. steam

Subtotal - \$0.00361486/lb TNT

Steam is used initially with each start-up to bring each purification washer and interconnecting line to operating temperature. This amount of steam was considered negligible and therefore was not used in these costs.

Cooling water

786 gal/min of cooling water is used to cool the entire manufacturing process. Only 25 percent of this is used for the purification phase.

786 gal/min x 60 min/hr x 24 hr/day x .25% x \$0.0001482/Gal
100,000 lb TNT/day

Subtotal - \$0.00041934/lb. TNT

Depreciation - 10 year straight line depreciation investment

Building and Services	\$261,288
Process Equipment	498,510
Process Piping	126,060
Instrument	64,176
Electrical Instrument, etc.	<u>71,052</u>

\$1,021,086

$$\frac{\$1,021,086/\text{capital investment}}{100,000 \text{ lb TNT/day} \times 350 \text{ day/yr} \times 10 \text{ yr/capital Invest.}} = \$0.0029174/\text{lb. TNT}$$

Chemicals (assume 100% conversion efficiency)

To make 580 lb/hr of $(\text{NH}_4)_2\text{SO}_3$

NH_3 - 170 lb	$\times \$139.382/\text{ton}$	=	\$11.84747/hr
SO_2 - 320 lb		=	63.908997/hr
H_2O - 90 lb	$\times \$0.0001482/\text{gal}$	=	<u>0.013338/hr</u>
			\$75.769805/hr

$$\frac{\$75.769805/\text{hr} \times 24 \text{ hr/day}}{100,000 \text{ lb TNT/day}} = \$0.0181848/\text{lb TNT}$$

Residue Loss @ \$0.456/lb

The ammonium sulfite purification system has a 1.0 percent α - TNT loss.
A 50-ton per day production rate requires 101,010 lb/day of crude TNT.

$$\frac{101,010 \text{ lb crude TNT/day} \times .01\% \times \$0.456/\text{lb crude TNT}}{100,000 \text{ lb TNT/day}} = \$0.004606/\text{lb. TNT}$$

Maintenance

(5 percent of the capital investment is used for maintenance cost)

$$\frac{\$1,021,086 \times .05/\text{year}}{100,000 \text{ lb. TNT/day} \times 350 \text{ days/year}} = \$0.00145869/\text{lb. TNT}$$

Total \$0.03174779/lb. TNT

B. Recovery

Labor - The recovery section requires 10 operators for a total cost of \$217,941.18 year, excluding overhead and fringe benefits. This is the minimum number of operators (1 per shift and 1 relief) for both the Oleum Plant section and the TNT section of Recovery operation.

$$\frac{\$217,941.18}{350 \text{ days/yr} \times 100,000 \text{ lb. TNT/day}} = \$0.00622689/\text{lb. TNT}$$

Electricity -

		HP/hr
(1)	20 HP Compressor (used 1/4 time)	5
(1)	3 HP Pump (Used 1/3 time)	1
(2)	40 HP Pumps to Red Water (1/4 time)	20
(1)	40 HP Pump to ammonia tower (1/2 time)	20
(1)	40 HP Mix tank Pump (1/4 time)	10
(1)	20 HP Storage tank pump (1/2 time)	10
		<u>66</u>

$$\frac{66 \text{ HP/hr} \times 24 \text{ hr/day} \times 0.7457 \text{ KWH/HP} \times \$0.031065/\text{KWH}}{100,000 \text{ lb. TNT/day}} =$$

\$0.00036697/lb. TNT

Steam - In evaporators

(2977 lb H₂O/hr must be evaporated to concentrate red water to 70% solids)

$$\frac{2977 \text{ lb H}_2\text{O/hr} \times 24 \text{ hr/day} \times 1006 \text{ BTU/lb H}_2\text{O} \times \$0.00378/\text{lb steam}}{100,000 \text{ lb TNT/day} \times 960.9 \text{ BTU/lb steam}} =$$

\$0.00282749/lb. TNT

Credit for energy evolved upon burning of the nitrobody in red water

$$243.21 \text{ lb. NB/hr} \times 6524.45 \text{ BTU/lb} = 1,586,811.48 \text{ BTU/hr}$$

Credit for energy evolved upon burning (NH₄)₂SO₄

$$659.72 \text{ lb (NH}_4\text{)}_2\text{SO}_4/\text{hr} \times 277 \text{ BTU/lb} = 182,742.44 \text{ BTU/hr}$$

$$\frac{1,769,553.92 \text{ BTU/hr} \times 24 \text{ hr/day} \times \$0.00378/\text{lb. steam}}{100,000 \text{ lb TNT/day} \times 960.9 \text{ BTU/lb steam}} = \$0.0016707/\text{lb TNT}$$

Subtotal \$0.0011568/lb. TNT

Water

(assume no waste and 100% conversion in the reaction of ammonia and sulfur dioxide)

Need 3335 lb H₂O/hr for dilution
 714 lb H₂O/hr for #2 acid washer
4049 lb H₂O/hr needed

$$\frac{4049 \text{ lb H}_2\text{O/hr} \times 24 \text{ hr/day} \times \$0.0001482/\text{gal H}_2\text{O}}{100,000 \text{ lb TNT/day} \times 8 \text{ lb H}_2\text{O/gal}} = \$0.00001800/\text{lb. TNT}$$

Depreciation - 10-year straight line depreciation investment

$$\frac{\$5,103,720}{350 \text{ day/yr} \times 10\text{-year} \times 100,000 \text{ lb TNT/day}} = \$0.01458206/\text{lb. TNT}$$

Chemical Credit for recovery

Assumption - Cost is the same to extract sulfur from sulfuric acid as from ammonium sulfate in the red water.

Operation of Oleum Plant

\$1,105,596 cost for 1979/15,353,966 lb of spend acid input

Cost of operating Oleum plant for 1979

Based on sulfur % input \$0.31499209733/lb sulfur

Red water feed into oleum plant 70% solids = 1191 lb/hr
 x 13.69% sulfur
163.05 lb sulfur/hr

Cost for extracting sulfur from the red water $\frac{163.06 \text{ lb sulfur/hr} \times \$0.31499209733/\text{lb sulfur}}{100,000 \text{ lb TNT/day}} = \$0.01232627/\text{lb. TNT}$

Credit for recovery of 100% of sulfur

$$\frac{\$56.63123/\text{hr} \times 24 \text{ hr/day}}{100,000 \text{ lb TNT/day}} = \$0.0135915^*/\text{lb. TNT}$$

* (Credit)

Subtotal \$0.0012652/lb. TNT

Compressed air (20 HP compressor)

$$\frac{20 \text{ HP/hr} \times 24 \text{ hr/day} \times 0.7457 \text{ KWH/HP} \times \$0.0031065/\text{KWH}}{100,000 \text{ lb TNT/day}} = \$0.00001119/\text{lb. TNT}$$

Subtotal \$0.00001119/lb. TNT

Maintenance (5% of capital investment)

$$\frac{\$5,103,720 \times .05 \text{ percent/year}}{100,000 \text{ lb.TNT/day} \times 350 \text{ days/year}} = \$0.0072910/\text{lb. TNT}$$

Subtotal \$0.0072910/lb. TNT

Total \$0.0283877/lb. TNT

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