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TECHNICAL REPORT ARLCD-TR-81033

**REMOVAL OF EXPLOSIVES FROM LOAD-ASSEMBLE-PACK
WASTEWATER (PINK WATER) USING SURFACTANT TECHNOLOGY**

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MAY 1982



**US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
LARGE CALIBER
WEAPON SYSTEMS LABORATORY
DOVER, NEW JERSEY**

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
Technical Report ARLCD-TR-81033	AD-A115 086	
4. TITLE (and Subtitle)		5. TYPE OF REPORT & PERIOD COVERED
REMOVAL OF EXPLOSIVES FROM LOAD-ASSEMBLE-PACK WASTEWATER (PINK WATER) USING SURFACTANT TECHNOLOGY		Final July 1979 - November 1980
7. AUTHOR(s)		6. PERFORMING ORG. REPORT NUMBER
Donald J. Freeman Olin A. Colitti		
9. PERFORMING ORGANIZATION NAME AND ADDRESS		8. CONTRACT OR GRANT NUMBER(s)
ARRADCOM, LCWSL Energetic Systems Process Div (DRDAR-LCM-SA) Dover, NJ 07801		
11. CONTROLLING OFFICE NAME AND ADDRESS		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
ARRADCOM, TSD STINFO Div (DRDAR-TSS) Dover, NJ 07801		MMT Project 5784214, Task 3
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		12. REPORT DATE
U.S. Army Munitions Production Base Modernization Agency ATTN: SARPM-PBM-E Dover, NJ 07801		May 1982
		13. NUMBER OF PAGES
		34
		15. SECURITY CLASS. (of this report)
		Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report)		
Approved for public release; distribution unlimited.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES		
This project was accomplished as part of the U.S. Army's Manufacturing Methods and Technology Program. The primary objective of this program is to develop, on a timely basis, manufacturing processes, techniques, and equipment for use in production of Army materiel.		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number)		
Trinitrotoluene (TNT)	Pink water	MMT-Pollution abatement
RDX	Alkaline hydrolysis	Diatomaceous earth filter
Composition B	Janovsky complex	Gas chromatographic analysis
Surfactant	Carbon adsorption	Liquid chromatographic analysis
Quaternary amine	Primary amine	Lagoons (cont)
20. ABSTRACT (Continue on reverse side if necessary and identify by block number)		
A study of surfactant treatment for ammunition plant wastewaters containing TNT and RDX (pink water) has shown that both of these toxic explosives can be removed from solution within 1 hour. The optimum conditions appear to be a combination of pH 11 and 0.4 mole of the quaternary surfactant (N, N, N', N', N' - pentamethyl N-tallow 1, 3 propane diammonium dichloride) for each mole of TNT in solution. The process has been determined to be technically feasible and economically attractive, although analytical techniques for determination of the degree of reaction must be improved. The cost of chemicals required (cont)		

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Block 19. (cont)

TNT-surfactant complex
Co-precipitation
Stoichiometric molar ratio

Block 20. (cont)

for the treatment (surfactant and sodium hydroxide) is about \$1.60 per 3,875 liters (1,000 gallons) of wastewater. The products of the treatment are a precipitated TNT-surfactant complex and a filtrate which contains RDX hydrolysis products, alkali, and possibly some yet-to-be-identified substances. It may be necessary to neutralize the filtrate before discharge since the final pH is about 10.5.

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INTRODUCTION

Previous work on the Pollution Abatement and Environmental Control Technology Program under Research and Development Project No. 1L76270D048 administered by the Chemical Systems Laboratory, ARRADCOM, demonstrated the feasibility of using surfactants to remove explosives dissolved in water (refs 1 and 2). The explosives of concern were TNT and RDX, the ingredients of Composition B explosive, since these have been discharged in large quantities in the wastewaters from both explosive manufacturing and ammunition loading plants in concentrations of approximately 120 ppm and 25 ppm, respectively.

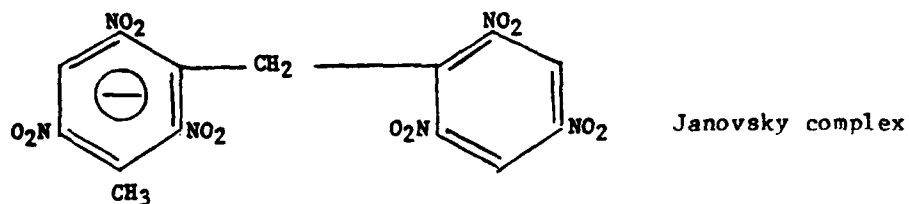
Although improvements in the manufacturing processes and decreased production levels during the past few years have drastically reduced the amount of TNT and RDX being discharged, the amount still remains significant. Photolysis products of the dissolved TNT are the compounds that cause the well-known pink water discharge, which is aesthetically, as well as environmentally, undesirable.

Both TNT and RDX are toxic¹ and yield positive Ames test results that are indicative of potential mutagenic and carcinogenic properties. Effluent guidelines of 10 ppb for TNT and 30 ppb for RDX have been proposed by the U. S. Army Medical Bioengineering Research and Development Laboratory (USAMBRDL) to the Surgeon General, even though the methods to reliably measure these low concentrations are still being developed. Neither TNT nor RDX is biodegraded under normal conditions in the environment or in biological waste treatment facilities. Some evidence exists that TNT is biotransformed into amine complexes--which are even more toxic than the original explosive (ref 3)--and that RDX is biodegraded slowly under anaerobic conditions. Although these substances may be removed from wastewaters with the use of carbon adsorption, the basic process is expensive and involves either an added expense for regeneration of the spent carbon or the creation of environmental problems associated with the disposal of the explosive-laden spent carbon.

Two types of surfactants have been demonstrated to be effective in the precipitation of TNT from solution. One is a surfactant in which the polar group is a primary amine and the other, a quaternary amine. The precipitation of TNT from solution is the result of the reaction between TNT and the surfactant in an alkaline medium to form an intermediate substance identified as the Janovsky complex (refs 1 and 2). This substance in turn reacts with the protonated surfactant and precipitates as a salt.

¹ Toxic levels of TNT and RDX in water (from USAMBRDL):

	<u>Toxicity to aquatic organisms</u>	<u>Toxicity to mammals</u>
TNT	60 ppb	44 ppb
RDX	300 ppb	34 ppb



In the case of RDX, it has been demonstrated that the surfactant accelerates the rate of alkaline hydrolysis of the RDX, rather than accelerating the formation of a precipitate. The increased rate of hydrolysis is probably due to the solubilization of the explosive by the surfactant micelles (oriented aggregation of surfactant ions or molecules) which concentrate the explosive and make it more available to the action of the alkali (ref 2). Thus, both TNT and RDX can be removed from a wastewater stream under the same alkaline-surfactant conditions.

On the basis of these findings, two bench-scale pilot studies were conducted at Hazards Research Corporation, Rockaway, New Jersey, to develop the process and, if possible, to obtain economic data. The first study was performed with TNT solution alone. Results showed that TNT could be readily removed. The surfactants found to be most effective were N-tallow 1, 3, diaminopropane (primary amine) and trimethyl tallow ammonium chloride (quaternary amine).

This report presents the results of the second study and describes further advances in the process, including the introduction of a new bifunctional quaternary amine surfactant (N, N, N', N', N' - pentamethyl N-tallow 1, 3 propane diammonium dichloride). The bench-scale pilot equipment used for the first study was also used for the second study. However, water containing dissolved Composition B (40% TNT and 60% RDX) was used in lieu of a TNT solution, thus simulating the wastewaters from the manufacture and loading of Composition B explosive.

DESIGN OF TEST PROGRAM

The test program was designed to permit a systematic evaluation of the factors which were considered to have a significant effect on the process. This test program is outlined in table 1.

Other changes in the test program (that included incorporation of the newest surfactant, Duoquad T-50, after the study was funded and the contract was awarded) did not permit complete evaluation of all parameters. Although high pH and high temperature seemed to offer advantages over the lower levels of those parameters, more detailed evaluation had to be postponed. A total of 17 test runs were made under preselected combinations of parameters. The values of the test parameters of each run are summarized in table 2.

The selection of surfactant-to-TNT molar ratios for the Arquad T-50 (0.75 and 0.60) and Duomeen T (2.0) was based on the results of prior work by Hazards Research Corporation and Polytechnic Institute of New York (PINY). The stoichiometric ratio for the reaction is 0.5 based on the reaction mechanism. The higher

molar ratios required for Duomeen T reflect the low ionization of this surfactant.

Since the Duoquad T-50 is bifunctional relative to the Arquad T-50, the required molar ratios were half the ratios required for Arquad T-50 (that is, 0.375, 0.30, 0.25, etc., for Duoquad T-50).

EXPERIMENTAL PROCEDURE

In general, the procedure shown below was followed for each run.

The treatment sample was prepared by weighing out sufficient Composition B to produce a solution containing approximately 120 ppm of TNT. For the 193.8 liter (50 gal.) mixtures used in each run, about 45.4 g (0.1 lb) of Composition B was required. The mixture was stirred overnight at the desired temperature, then filtered to remove undissolved RDX², and subsequently pumped into the batch reaction tank. A sample was then taken for analysis of the initial TNT and RDX content. The arrangement of pilot test equipment is shown in figure 2.

After the amount of dissolved TNT was determined, a weighed amount of surfactant was added to give the desired molar ratio. The addition of the surfactant produced a red color, but little or no precipitate was formed. After the surfactant was mixed in, a sample was taken for determination of initial TOC content. Sodium hydroxide solution was then added until the desired pH was attained. The mixture in the reaction tank was stirred continuously during the entire reaction time. Fifteen minutes after the pH was adjusted, a portion of the reaction mixture was drained through a filter bag of one micron porosity, and a sample was collected for analysis. The same procedure was followed 2 hours after pH adjustment and again 5 hours after pH adjustment. Before analysis, the samples were again filtered through diatomaceous earth in a laboratory Buchner funnel to remove all traces of particulate matter. Because of the high pH of the alkaline reaction mix, all samples for analysis were neutralized to a pH of 7 with HCl to prevent further reaction.

A straw-colored filtrate was obtained. The color intensity of the filtrate relates to both the duration of treatment and the initial molar ratio of surfactant to TNT.

² Solubility of TNT is approximately 150 ppm at 25°C, whereas the solubility of RDX is approximately 25 ppm; thus a solution made up of 120 ppm TNT (and 180 ppm of available RDX) using Composition B will have excess undissolved RDX (fig. 1, ref 4).

ANALYTICAL INSTRUMENTATION

The following instruments were used in this study:

Gas Chromatograph (Hazards Research Corporation)

Gas chromatograph, Perkin-Elmer Model Sigma 3, with dual flame ionization detectors and dual heated flash vaporization injectors.

Three foot x 1/2 inch glass column, 10% UC-W-98 on Chrom G AWMCS (60-80 mesh).

L & N Speedomax W potentiometric recorder

Liquid Chromatograph (Polytech Institute of New York)

High performance liquid chromatograph, Waters Associates Model ALC-GPC-201, including:

Model 440 uv detector

Model R-401 differential refractometer detector

Model U6K universal injector

Model 6000A solvent recovery system

Heathkit Model EU-20A single pen recorder

Waters Associates 61 cm x 2 mm Bondapak C₁₈ reverse phase column, chemically bonded layer of octadecylsilane (Si-C₁₈) on a solid glass bead support (37-50 μ particle size).

Total Organic Carbon (TOC) Analyzer (Hazards Research Corporation)

Organic carbon analyzer, Beckman Instruments Model 915A

Infrared analyzer, Beckman Instruments Model 856

Strip chart recorder, Texas Instruments Model FS01WS0

Constant rate syringe, Hamilton Model CR-700-50

Spectrophotometer, (Hazards Research Corporation)

Spectrophotometer, Bausch & Lomb Spectronics 20 Model 33-31-72

DISCUSSION OF RESULTS

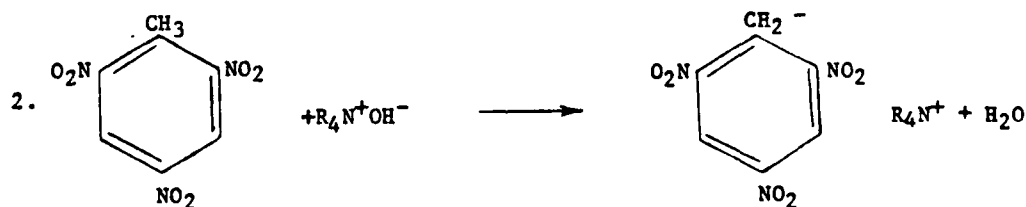
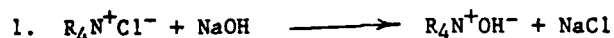
TNT Removal

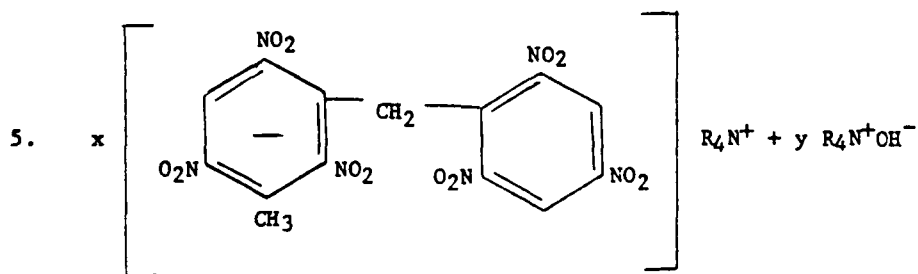
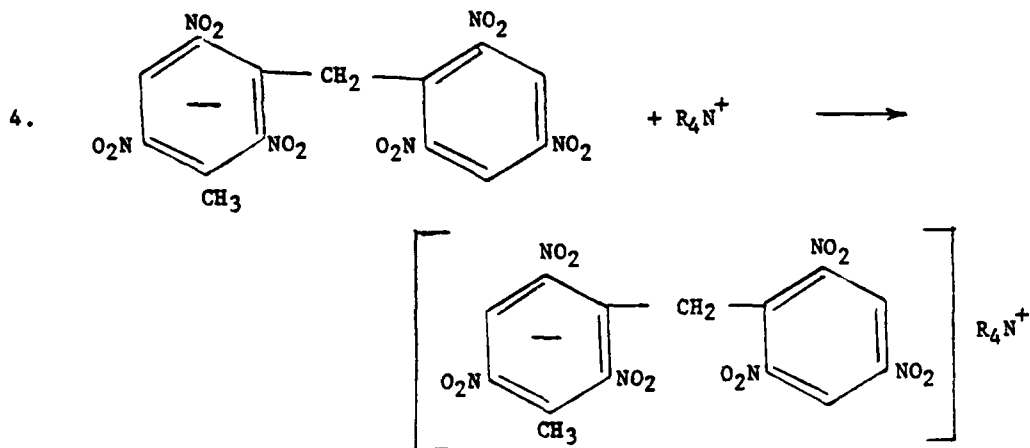
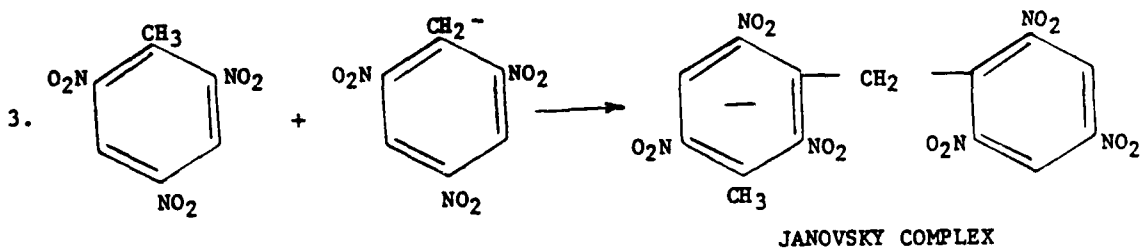
The TNT concentrations remaining after surfactant treatment were determined by the gas chromatographic method by use of a flame ionization detector (FID). The analytical results are shown in table 3. After 5 hours of treatment, all TNT was apparently removed from the Composition B water having an initial TNT concentration of about 100 ppm (regardless of the surfactant, pH or temperature used) as indicated by the gas chromatograph (GC)/FID having a detection level of only 0.1 ppm (100 ppb). However, the proposed effluent guideline for TNT is 10 ppb, and a goal of 5 ppb or less has been set for the detection level when a GC with electron capture detector (ECD) is used. Ongoing studies of this process at Louisiana Army Ammunition Plant are expected to produce refinements of the data on the reaction rate and the degree of completion of the TNT-surfactant reaction.

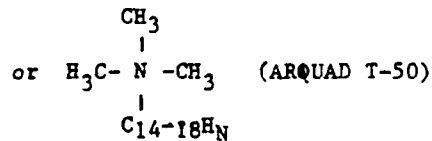
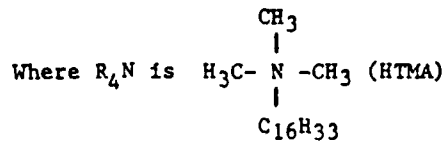
The TNT concentration data in table 3 indicates that at the stoichiometric molar ratio of 0.25 (for the bifunctional Duoquad T-50, as based on the 0.50 molar ratio in the reaction equations for monofunctional Araquad T-50) the reaction did not go to completion in 5 hours. However, as excess surfactant is added, the reaction apparently goes to completion within a period of 15 minutes to 1 hour afterward.

A more detailed reaction-time profile of the TNT and TOC content was made for the Duoquad T-50 run at the 0.35 molar ratio in the less-than-1-hour time-frame because of the high reaction rate (table 4). Although little data at pH 12 and at a reaction temperature of 55°C is available, further evaluation of these parameters may be worthwhile.

As mentioned previously, the reaction between TNT and an amine surfactant involves the formation of an intermediate, designated as the Janovsky complex, discovered by Janovsky and Erb in 1886 (ref 1 and 2). Dr. Y. Okamoto of PINY was separately funded to study this reaction and to determine the chemical structure of the complex formed. This work (currently being prepared for publication) has resulted in the finalization of the following reaction mechanism:



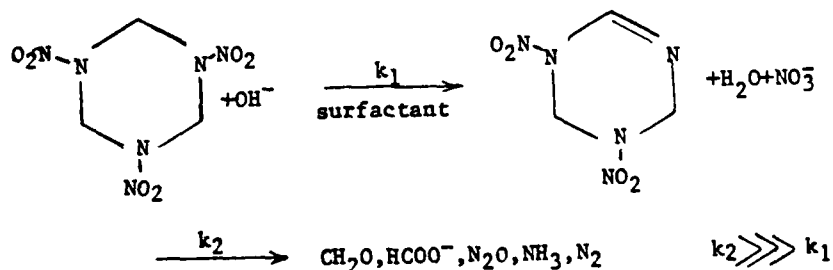




Note: The quantities "x" and "y" [or (1 - x)] are variables dependent on the amount of excess surfactant added to the solution being treated.

Further credence for the structure of the complex is provided by the TOC data in table 5, which indicate very little increase in TOC after completion of reaction, while increases in the molar ratio resulted in large increases in the initial TOC. The TOC is the result of all carbon sources in solution: surfactant, TNT, RDX, RDX hydrolysis products, and other dissolved TNT and RDX impurities, after correction for TOC in the water used and atmospheric CO_2 reacting with the alkaline solution during mixing.

The equations for the alkaline hydrolysis of RDX are (refs 5 and 6):



Thus, after completion of the reaction, the reported TOC represents the degradation products--formaldehyde and formates, resulting from RDX hydrolysis, plus any other impurities not reacting.

Although the original plan did not consider filtrate color as a factor, the accumulation of data led to the observation that the filtrates varied in color from almost clear or colorless to dark amber. A sample of a 5-hour filtrate was passed through a carbon column to remove the color. The TOC of the resultant colorless solution was reduced by only 1 to 2 ppm, indicating a very small quantity of an intensely colored substance. Some of the precipitate was washed until the filtrate was colorless, and the precipitate was then mixed in a pH 11 sodium

hydroxide solution for 5 hours. Because the resulting solution had a yellowish color, it was thus concluded that the precipitate should be removed from the reaction vessel as soon as it is formed, to prevent coloration from the reaction of the precipitate with the filtrate. Even if nontoxic and noncarcinogenic, the compounds responsible for the color should be removed or minimized for aesthetic reasons.

For one test run (0.40 molar ratio of Duoquad T-50), a recycle line with constant filtration through the filter bags was set up. To quantify color variation, color absorption at 460 nm was measured with a Bausch & Lomb Spectrophotometer by use of a 25.4 mm (1-in.) path length. In addition to the recycle-filtration run, filtrate samples from all other Duoquad T-50 runs were available for color measurement, thus permitting comparisons. From table 6, it is apparent that the color intensity (1) increases with reaction time, (2) tends to decrease with increasing molar ratio, and (3) is generally lower during the continuous filtration run. The intense color of the lower molar ratio runs is due to a reaction between TNT and sodium hydroxide when the surfactant is not available in excessive amounts.

RDX Removal

RDX concentrations were initially determined by use of the GC/FID, but the resulting RDX values were extremely low and erratic, indicating that the method was not appropriate for the analysis of RDX. Arrangements were subsequently made for PINY to analyze the samples by use of PINY's high performance liquid chromatograph (HPLC) (table 7). As discussed previously, the RDX is decomposed by alkaline hydrolysis into liquid and gaseous products, in contrast to the TNT, which is precipitated after formation of an insoluble complex with the surfactant. The active ingredient is the alkali, but surfactant is required to catalyze the reaction. Since the carbonaceous products are still in solution, the TOC contribution from RDX should remain constant throughout the reaction period.

Because of problems with the analysis of RDX and because the initial RDX concentrations were erratic, numerous data points are missing for the RDX concentration data in table 7. The use of gas chromatography with FID had been recommended for the analysis of RDX, but problems were encountered almost immediately--although not recognized because of the solubility characteristics of RDX. As shown in figure 2, not only is the solubility of RDX low (such that Composition B solutions were always saturated with respect to RDX--but not with respect to TNT), but the solubility is extremely temperature-sensitive, increasing by 1700% over the temperature range of this study.

When it was finally determined that the RDX was decomposing in the GC, analysis with the GC was discontinued. The samples were then analyzed for RDX content by use of PINY's high performance liquid chromatograph (HPLC). Although previously analyzed samples were saved for re-analysis, several samples were no longer available.

The data in table 7 indicates that the RDX concentration reached its lowest point (apparently 0 ppm) on three runs in a reaction time of 15 minutes to 2

hours, then increased. This phenomenon was discussed with Dr. Okamoto of PINY, and the explanation for the phenomenon lies in the formation of soluble reaction products whose peaks interfered with the RDX peaks on the chromatogram. This phenomenon can be eliminated by refinement of the HPLC analytical procedure in future work.

As with the GC/FID, precision of the HPLC results was limited by the equipment and analytical techniques to a detection level of about 100 ppb, even though the proposed effluent guideline for RDX is 30 ppb. A procedure was developed to achieve a detection level of 30 ppb by use of a GC with an ECD. However, the RDX decomposition problems arose again. At present an intensive effort is being made to improve the detection levels attainable with the HPLC.

Process Evaluation

Both TNT and RDX have been quantitatively removed from Composition E solution with surfactants in an alkaline solution. Although the three surfactants were equally effective for explosives removal, the Duomeen T and Arquad T-50 have been eliminated from further consideration. Duomeen T was eliminated because (1) it is difficult to handle and to place in solution since it is a pasty, low-solubility solid, (2) it forms a fine, slow settling, filter-clogging precipitate upon reaction with TNT, and (3) it is more costly than either Arquad or Duoquad (table 8). Arquad T-50 was eliminated in favor of Duoquad T-50 simply on the basis that half as much Duoquad is required, thus reducing the material cost and the generation of waste material to be disposed of.

For Duoquad T-50, which is the surfactant of choice, the cost would range from \$1.00 to \$1.33 per 1,000 gallons of wastewater with a 120-ppm TNT content. Approximately 0.908 kg (2 lb) of sodium hydroxide would be required to bring the pH to 11 in 3,875 liters (1,000 gal.) of this wastewater. At \$0.19/0.454 kg (1 lb) for sodium hydroxide, the total cost for chemicals to treat 3,875 liters of Composition B wastewater would range from \$1.38 to \$1.71. Total treatment costs will be developed from planned pilot studies. It is anticipated that these costs will compare favorably with carbon adsorption, which is estimated to cost between \$6 and \$7 per 3,875 liters of 120-ppm TNT wastewater. In addition, no more than 0.672 kg (1.48 lb) of precipitate will be formed for 3,875 liters of wastewater treated. This waste can be incinerated at minimal cost.

The removal of TNT with Duoquad T-50 was marginal at or slightly above the stoichiometric surfactant-TNT molar ratio, but became quite efficient as the molar ratio exceeded 0.375. Conversely, the removal of RDX was not affected by the molar ratio. This result was not unexpected, since the surfactant merely catalyzes the RDX removal. The available data, however, is not sufficient to determine whether reaction efficiency will be significantly affected by raising the pH from 11 to 12, raising the temperature from 25°C to 55°C, or both. Funding limitations did not allow further investigation of these parameters.

Another area requiring further investigation is the analysis of the filtrate with respect to both its initial composition and its composition after contact with the precipitate. This data is necessary to define the optimum process con-

ditions, to verify the assumed reaction mechanisms, and to identify any toxic or carcinogenic products.

CONCLUSIONS

1. The surfactant process can be used to effectively remove both TNT and RDX from Composition B wastewater (also known as pink water), with the bifunctional quaternary Duoquad T-50 being the most promising surfactant evaluated.

2. Other reaction parameters include a pH of 11 (with sodium hydroxide addition) and a temperature of 25°C.

3. Further evaluation is needed to determine whether elevated temperatures (to 55°C) and pH (to 12) will enhance reaction efficiency.

4. The surfactant process has two products: a very small amount of co-precipitated TNT-surfactant complex and excess surfactant (which can be easily incinerated), and a filtrate which, after further identification of its components, may be suitable either for direct discharge or for conventional wastewater treatment, with or without neutralization.

5. Although sufficient data is not yet available for a valid cost comparison, the surfactant process may provide an economic alternative to the use of carbon adsorption for the removal of explosives from wastewater streams from the standpoint of both process costs and disposal of process waste products.

6. The fine tuning of this process has been limited by the lack of appropriate analytical procedures for TNT and RDX--procedures with sufficient precision and lower detection levels to provide a meaningful evaluation of the process parameters.

CURRENT STATUS

Further advancements in the state-of-the-art of this technology are expected from three studies now in progress:

1. An extension of the application of the surfactant-explosive reaction is being studied under "Tetryl Fixation in Water" at Polytechnic Institute of New York (PINY). Tetryl is a booster explosive that is no longer manufactured but has contaminated the soil and waters at some Army ammunition plants. Feasibility studies have indicated that surfactants are effective in removing tetryl from solution.

2. "Fixation and Removal of Explosives from Pink Water" is a two-year project now underway at Louisiana Army Ammunition Plant (LAAP). The purpose of this study is to apply the information gained from the Hazards Research Corporation work to the design of a continuous bench-scale process for the removal of TNT and RDX directly from the wastewater stream of an operating load, assemble,

and pack line at LAAP. This process will incorporate continuous removal of the precipitated complex. Other areas to be studied include further evaluation of reaction parameters (such as temperature and pH) and the composition of the effluent stream.

3. Removal of RDX and TNT from lagoon waters is being studied at Louisiana Army Ammunition Plant under an installation restoration study, "Fixation of Explosives in Lagoon Water." This study is aimed at removing explosives that have been dumped in Army ammunition plant lagoons over the years, and the study may reveal further pollution problems in the future. This two-year study will interface with the tetryl study now underway at PINY. The techniques for determining TNT in the 1-to-5-ppb range and RDX in the 3-to-11-ppb range are being developed as part of this work.

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Table 1. Test program

<u>Parameter</u>	<u>Description and conditions</u>
Surfactant	
Primary amine	N-tallow diaminopropane (Duomeen T ^a)
Quaternary amines	Trimethyltallow ammonium chloride (Arquad T-50 ^a) N, N, N', N' N' - pentamethyl - N-tallow-1, 3- propane diammonium dichloride (Duoquad T-50 ^a)
pH	11 ± 0.25 and 12 ± 0.25
Temperature	25° ± 10°C and 55° ± 10°C
Reaction time	0, 1, 3, 6, 24 hours ^b

^a Product name of Armak Chemical Co., Inc., Chicago, Illinois.

^b Sampling times as originally designated. The 24-hour test was subsequently deleted, and the remaining sampling times were changed to 0.25, 2, and 5 hours when the high rate of reaction was confirmed.

Table 2. Test parameters

<u>Surfactant</u>	<u>Molar ratio of surfactant to TNT</u>	<u>Temperature (°C ± 10°C)</u>	<u>pH (± 0.25)</u>
Arquad T-50	0.75	25	11
	0.75	55	11
	0.75	55	12
	0.60	55	12
	0.75	25	12
	0.75	25	11
	0.60	25	11
Duomeen T	2.0	25	11
	2.0	55	11
	2.0	55	12
Duoquad T-50	0.375	25	11
	0.25	25	11
	0.30	25	11
	0.45	25	12
	0.45	25	11
	0.40	25	11
	0.35	25	11

Table 3. Effect of surfactant-TNT molar ratio on TNT in Comp B water

PPM TNT remaining at end of reaction time									
Reaction time (hr)	Surfactant								
	Arquad T-50		Duoquad T-50						
2.0	0.75	0.60	0.45	0.40	0.375	0.35	0.30	0.25	
Molar ratio									
pH: 11.0 ± 0.25 - Temp: 25 ± 10°C									
0	92	93	96	108	91	91	98	105	
0.25	1	2	1	0	0.1	2	4	9	
2	0	0.5	0	0	0	0	0.5	1.5	
5	0	0	0	0	0	0	0	0.1	
pH: 11.0 ± 0.25 - Temp: 55 ± 10°C									
0	121								
0.25	2								
2	0								
5	0								
pH: 12.0 ± 0.25 - Temp: 25 ± 10°C									
0	110		117						
0.25	0		0						
2	0		0						
5	0		0						
pH: 12.0 ± 0.25 - Temp: 55 ± 10°C									
0	129	119							
0.25	0	0							
2	0	0							
5	0	0							

Table 4. Reaction time profile of TNT and TOC content for 0.35 molar ratio of Duoquad T-50 at 25°C and pH 11

<u>Reaction time (min)</u>	<u>ppm TNT</u>	<u>ppm TOC</u>
0	91	139
5	13.6	42
15	1.6	38
25	1.3	38
40	0.4	38
60	0.2	37
90	0	37
120	0	41
180	0	-
240	0	41

Table 5. Effect of Duoquad T-50 TNT molar ratio on TOC in Comp B water at 25°C and pH 11

<u>Reaction time (hr)</u>	<u>ppm TOC</u>					
	<u>Molar ratio</u>					
	<u>0.45</u>	<u>0.40</u>	<u>0.375</u>	<u>0.35</u>	<u>0.30</u>	<u>0.25</u>
0	232	152	145	139	165	119
0.25	58	51	52	38	58	30
2	-	54	38	41	37	22
5	59	58	57	41	36	20

Table 6. Effect of Duoquad T-50/TNT molar ratio on color intensity of Comp B water at 25°C and pH 11

Reaction time (hr)	Absorbance at 460 nm					
	Molar ratio					
	<u>0.45</u>	<u>0.40</u>	<u>0.375</u>	<u>0.35</u>	<u>0.30</u>	<u>0.25</u>
0	0.00	0.00	0.00	0.00	0.00	0.00
0.25	0.04	0.04*	0.07	0.17	0.31	0.55
2	0.14	0.17*	0.21	0.18	0.29	0.33
5	0.24	0.18*	0.30	0.26	0.36	0.41

* Continuous filtration.

Table 7. Effect of surfactant-TNT molar ratio on RDX in Comp B water

Reaction time (hr)	PPM TNT remaining at end of reaction time									
	Surfactant					Surfactant				
	Arquad T-50		Duoquad T-50			Arquad T-50		Duoquad T-50		
	0.75	0.60	0.45	0.40	0.375	0.35	0.30	0.25		
	pH: 11.0 ± 0.25 - Temp: 25 ± 10°C									
0	90	57	29.8	31.0	*	32.0	45.4	85.4		
0.25	0.6	0.9	0.9	1.3	0.5	2.6	0.5	0.4		
2	0.5	0	0	2.6	0.1	4.4	0	0.1		
5	1.0	10.7	2.25	5.3	2.1	2.9	1.75	0.7		
	pH: 11.0 ± 0.25 - Temp: 55 ± 10°C									
0	*									
0.25	0.5									
2	*									
5	0.5									
	pH: 12.0 ± 0.25 - Temp: 25 ± 10°C									
0	68		45							
0.25	0.1		1.5							
2	*		0.1							
5	0.2		0.4							
	pH: 12.0 ± 0.25 - Temp: 55 ± 10°C									
0	94	81								
0.25	*	0.9								
2	*	*								
5	0.5	0.5								

* Samples not available for HPLC analysis.

Table 8. Surfactant costs for removal of 0.454 kg (1 lb) of TNT per 3,875 L (1,000 gal.)*

Surfactant	Molecular weight	Activity (%)	Moles of surfactant per mole of TNT	Surfactant required (0.454 kg/3875 L) (1b/1,000 gal.)	Surfactant cost (\$/0.454 kg (1b))	Surfactant cost (\$/3875 L (1,000 gal.))
Duomeen T	350	100	2	3.20	0.81	2.59
Arquad T-50	340	50	0.75 0.60	2.25 1.80	0.65	1.46 1.17
Duoquad T-50	486	50	0.40 0.375 0.30	2.63 1.53 1.22	0.82	1.33 1.25 1.00

* Equivalent to 0.00053 moles or 120 mg/L of TNT.

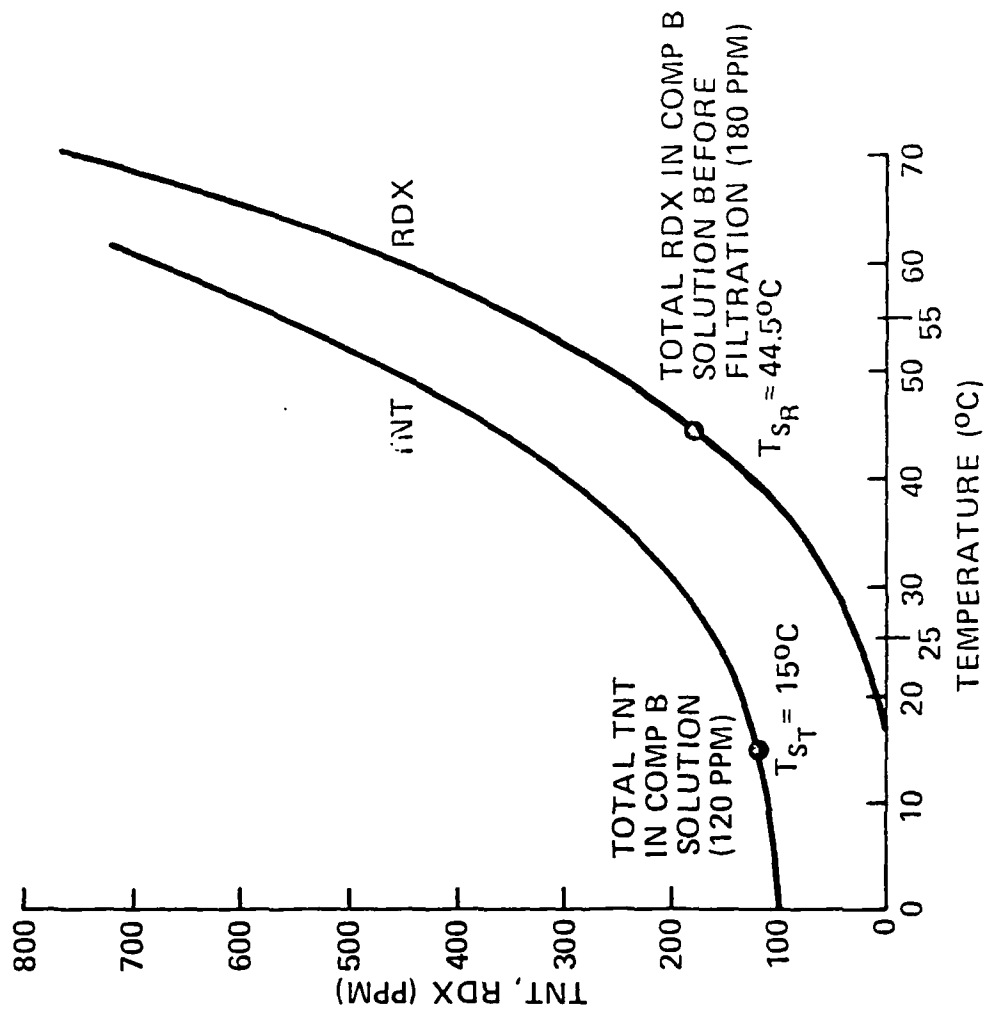


Figure 1. Solubility of TNT and RDX in water (ref 4)

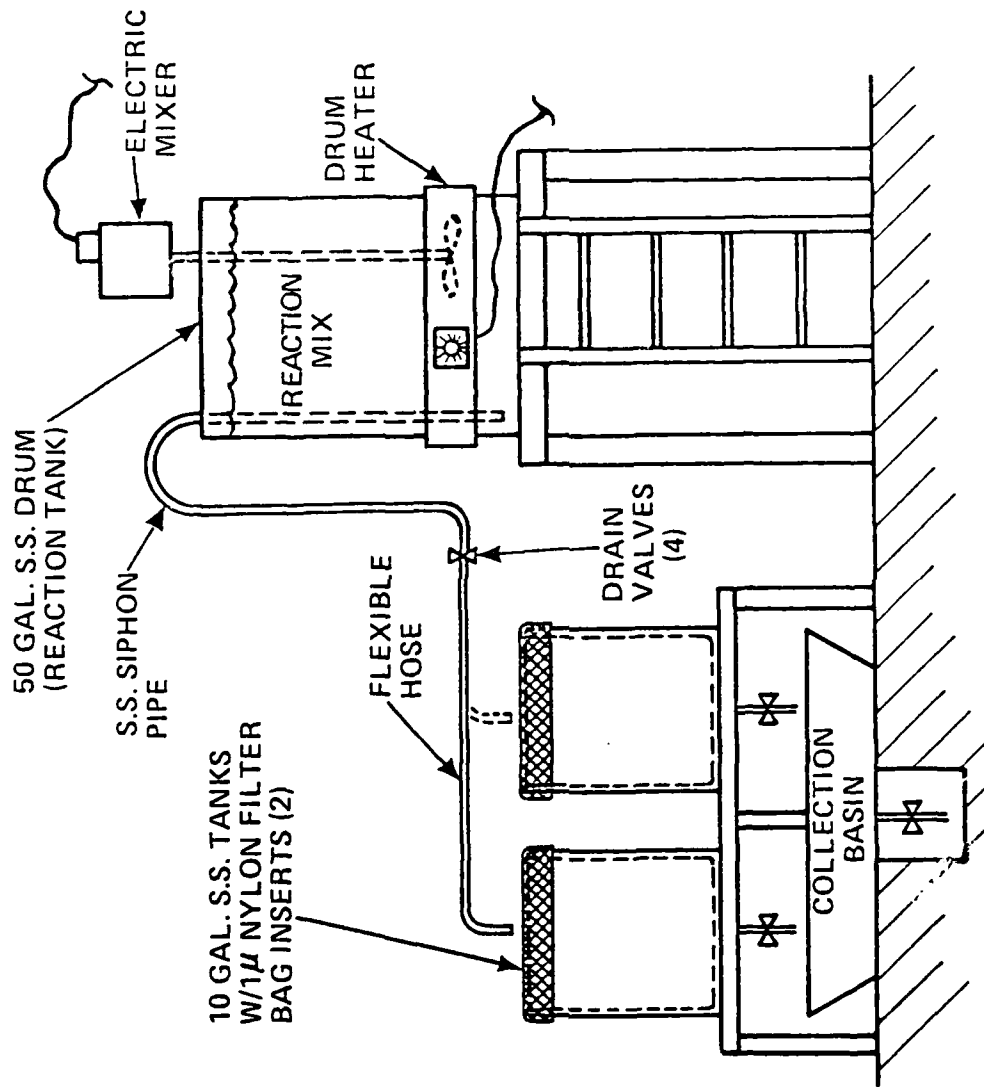


Figure 2. Surfactant pilot plant

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