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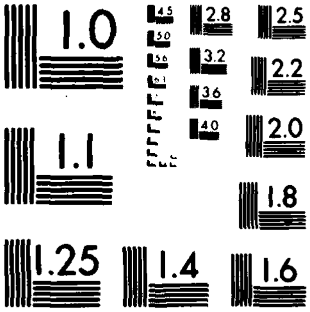
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PREPARATION AND PURIFICATION OF HMX AND RDX INTERMEDIATES (TAX AND SEX)

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1-Acetylhexahydro-3,5-dinitro-1,3,5-triazine
1-Acetyloctahydro-3,5,7-trinitro-1,3,5,7-tetrazocine
1,5-Diacetyloctahydro-3,7-dinitro-1,3,5,7-tetrazocine
1,3,5,7-Tetranitro-1,3,5,7-tetrazocine
1,3,5-Trinitro-1,3,5-triazine
1,3,5-Triacetylhexahydro-1,3,5-triazine
Synthesis
Nitrolysis
Purification

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report describes the feasibility of preparing 4 kg each of 1-acetylhexahydro-3,5-dinitro-1,3,5-triazine (TAX) and 1-acetyloctahydro-3,5,7-trinitro-1,3,5,7-tetrazocine (SEX). TAX was prepared by nitrolysis of 1,3,5-triacetylhexahydro-1,3,5-triazine (TRAT) using a mixture of trifluoroacetic anhydride (TFAA) and 100% nitric acid. The crude TAX, contaminated with 5% to 30% RDX, was obtained analytically pure (99.9+%) by open column chromatography on silica gel using a 1:1 mixture of nitromethane/dichloromethane as eluent. A

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plug-flow continuous design was found to be a rapid, efficient, and safe method for the projected synthesis of TAX in kilogram quantities.

SEX was prepared by nitrolysis of 1,5-diacetyloctahydro-3,7-dinitro-1,3,5,7-tetrazocine (DADN) using a mixture of trifluoroacetic anhydride and 100% nitric acid. The crude SEX was contaminated with 50% DADN, HMX, or both, depending on the reaction conditions. Soxhlet extraction of the crude SEX with ethyl acetate affords 80% SEX with 20% DADN contaminated. Because the major problem is not the synthesis of SEX but its purification, additional methods for purification and further examination of solvent systems used for extractive and chromatographic separations should be explored to obtain analytically pure SEX.

SUMMARY

This final report describes the feasibility of preparing 4 kg each of 1-acetylhexahydro-3,5-dinitro-1,3,5-triazine (TAX) and 1-acetyloctahydro-3,5,7-trinitro-1,3,5,7-tetrazocine (SEX). The objectives were to (1) establish the technical feasibility of producing amounts of SEX and TAX needed for toxicological testing (about 4 kg of each), (2) provide these materials in satisfactory purity and with proper analytical characterization of residual impurities, and (3) provide a firm price estimate for preparation of the compounds.

TAX was prepared by nitrolysis of 1,3,5-triacetylhexahydro-1,3,5-triazine (TRAT) using a mixture of trifluoroacetic anhydride and 100% nitric acid. The crude TAX, contaminated with 5% to 30% RDX, was obtained analytically pure (99.9+%) by open column chromatography on silica gel using a 1:1 mixture of nitromethane/dichloromethane as eluent. The safety and heat removal problems that would be encountered during the synthesis of kilogram quantities of TAX prompted an examination of continuous preparative systems. A plug-flow reactor design was found to be a rapid and efficient method for the preparation of TAX. Thus, TAX can be provided in the quantities desired for subsequent purification.

Characterization of the shock-sensitivity of TAX showed that it can sustain greater than 300 kg-cm in a drop weight test (compared with 134 kg-cm for pure RDX). TAX is insensitive to direct, strong hammer blows and has not exhibited any sensitivity hazards during these studies.

SEX was prepared by nitrolysis of 1,5-diacetyloctahydro-3,7-dinitro-1,3,5,7-tetrazocine (DADN) using a mixture of trifluoroacetic anhydride and 100% nitric acid. The crude SEX was contaminated with 50% DADN, HMX, or both, depending on the reaction conditions.

Soxhlet extraction of a crude SEX mixture (40% SEX/60% DADN) with ethyl acetate resulted in a maximum purity of 80% SEX. All other purification methods such as crystallization, column chromatography, or centrifugation failed to improve the purity of the crude SEX. The major problem is not the synthesis of SEX but its separation from these major contaminants. Alternative synthesis routes to SEX that preclude the formation of DADN or HMX should be explored. Furthermore, additional methods for purification and further examination of solvent systems used for extraction and chromatographic separations should be examined.

A cost estimate for preparation of 4 kg each of SEX and TAX in the purity needed for toxicological studies of these compounds is being submitted as part of SRI Proposal PYU 80-133.

CONTENTS

GLOSSARY

DADN - 1,5-Diacetyloctahydro-3,7-dinitro-1,3,5,7-tetrazocine

FEP - Fluorinated ethylene-propylene polymer

HMX - 1,3,5,7-Tetranitro-1,3,5,7-tetrazocine

HPLC - High pressure liquid chromatography

IPA - Isopropyl alcohol

NMR - Nuclear magnetic resonance

RDX - 1,3,5-Trinitro-1,3,5-triazine

SEX - 1-Acetyloctahydro-3,5,7-trinitro-1,3,5,7-tetrazocine

TAT - 1,3,5,7-Tetraacetyloctahydro-1,3,5,7-tetrazocine

TAX - 1-Acetylhexahydro-3,5-dinitro-1,3,5-triazine

TFAA - Trifluoroacetic anhydride

TLC - Thin layer chromatography

TRAT - 1,3,5-Triacetylhexahydro-1,3,5-triazine

INTRODUCTION

The U.S. Army Medical Research and Development Command is interested in determining the potential enviromental and health hazards of wastewaters containing SEX and TAX. SEX and TAX are unavoidable co-products formed during the manufacturing of RDX/HMX. In 1977, 34,000 pounds of HMX were produced, or about 123 pounds per day. At full production levels, more than 1000 pounds per day of SEX and 3600 pounds per day of TAX could be generated and discharged. The wastewaters from the manufacturing of RDX/HMX are subject to environmental discharge limitations established by regulatory agencies. Evaluation of the potential hazards of these wastewaters to the environment is a necessary portion of the data base needed to estimate environmental criteria. Because these wastewaters will contain large amounts of both SEX and TAX, it is important to obtain sufficient quantities of pure SEX and TAX for a complete toxicological investigation.

Since SEX and TAX are of no value as explosives, little effort has been directed at their deliberate synthesis. Therefore, we investigated the feasibility of preparing 4 kg each of SEX and TAX in the purity ($\geq$ 98%) necessary for these studies. The specific objectives of the study were as follows:

(1) Investigate the most promising methods reported for the preparation of SEX and TAX and verify successful syntheses on a 50-g batch scale.

(2) Investigate both known and alternative purification methods for SEX and TAX to determine which is the most effective.

(3) Determine the most efficient methodology for the analysis of both SEX and TAX.

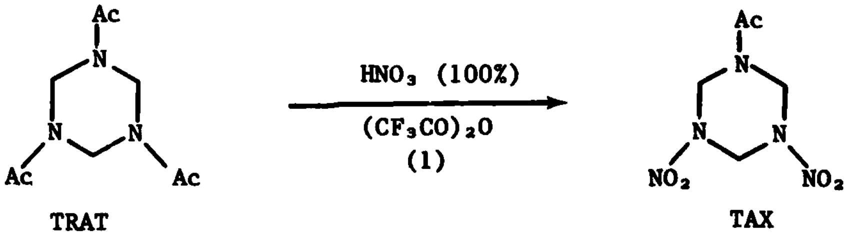
(4) Further characterize SEX and TAX by determining their shock-sensitivity so as to permit their classification for shipping, handling, and storing.

(5) Prepare a final report fully documenting the information pertaining to this study and include a best-efforts cost estimate for the production of the required quantities of SEX and TAX.

The results of our efforts to prepare, purify, and characterize TAX and SEX are described in the following sections.

PREPARATION OF TAX

TAX was prepared according to the method of Gilbert et al.,* as shown in Equation (1).



Treatment of 1.4 to 6.0 g (7 to 31 mmole) of dry TRAT with a mixture of nitric acid (100%) and trifluoroacetic anhydride (TFAA) consistently yielded 60% to 70% of crude TAX, as listed in Table 1. The synthesis, although successful, had three serious drawbacks. First, the amount of TFAA used in the reaction procedure described by Gilbert et al. represented a substantial materials cost, making the preparation of 4-kg quantities of TAX prohibitively expensive. Second, the reaction is exothermic, making the large-scale production of TAX (4-kg quantities) impractical because of the hazardous conditions encountered when handling large quantities of materials. Third, the crude TAX was contaminated with 5% to 30% RDX, which could be effectively removed only by open column chromatography. To prepare TAX in the quantities required by the contract and at a reasonable cost, the above problem had to be solved.

TFAA Cost

TFAA can be purchased in bulk from Halocarbon Products Corporation for \$15/pound. The quantity of TFAA used for the production of 4 kg

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*E. E. Gilbert, J. R. Leccacorvi and M. Warman, "Industrial and Laboratory Nitrations," ACS Symposium Series 22, R. F. Gould, Ed., Washington, D.C., 1976, p. 337.

Table 1

SYNTHESIS OF TAX BY NITROLYSIS OF TRAT IN HNO$_3$ (100%)/TFAA

Run	TRAT g (mmole)	TFAA, g (mmole)	Temp.,[a] °C	Time, min	Yield, g (%)	TAX:RDX[b]
1	1.4 (7.0)	15.2 (73.0)	35	45	1.11 (67.5)	
2	1.4 (7.0)	15.2 (73.0)	38	40	1.20 (72.9)	
3	6.0 (31.0)	75 (365.0)	40	45	4.95 (70.2)	
4	1.4 (7.0)	15.2 (73.0)	40	50	1.25 (74.0)	
5	1.4 (7.0)	15.2 (73.0)	40	50	1.20 (72.9)	
6	1.4 (7.0)	7.6 (36.5)	36	15	1.03 (63.0)	95:5
				25		82:18
				40		52:48
				55		50:50
7	1.4 (7.0)	7.6 (36.5)	26	15	0.98 (58.0)	95:5

[a] Maximum temperature reached during reaction exotherm.

[b] Composition determined by either proton NMR or analytical HPLC.

of TAX, as described in the Gilbert method, would cost approximately \$7,000. We found that halving the amount of TFAA used in the reaction had little effect on the yield or purity of TAX (see runs 6 and 7, Table 1). The reaction conditions require that the TRAT be dissolved in TFAA before mixing with 100% HNO_3. As a result, further reductions in the amount of TFAA are impractical because of solvation problem such as precipitation of the dissolved TRAT out of the solvent during addition to the reaction chamber and the inherent volatility of TFAA (bp 40°C). Combined with improved yields of TAX, the conditions we have developed for the preparation of 4 kg of TAX has reduced the TFAA cost to about \$2,000, a substantial savings over the initial procedure.

To obtain pure TAX two major problems had to be addressed: synthesis and purification. Since, purification of the TAX obtained by the above described method would still be required, we briefly explored the possibility of replacing TFAA with the more economical acetic anhydride. Under a variety of conditions, reaction of TRAT with a acetic anhydride/HNO_3 (100%) mixture failed to yield detectable amounts of TAX. This alternative route was abandoned, and efforts were concentrated on the use of TFAA as the only feasible route to TAX.

Reaction Exotherm

The experimental method described by Gilbert et al., requires that the reaction mixture be cooled during the reaction. After admixture of all the components, a brief induction period occurred after which, without external cooling, an internal temperature of 60°C was reached when using only 1.4 g of TRAT. At this temperature the TFAA is driven off, its boiling point being only 40°C. On scale-up, effective cooling of the reaction mixture in conventional batch equipment becomes difficult because of the change in the ratio of the volume of material to the effective surface area used for cooling.

This problem was solved by using a continuous plug-flow method for the preparation of TAX. For example, 7.2 g (34 mmole) of TRAT dissolved in 25 ml (37.5 g) of TFAA was mixed with 10 ml of 100% HNO_3.

A residence time of 18 minutes was obtained by passing the mixture through a helical coil followed by quenching the effluent in an ice/water bath. A 4.3-g (62.4%) yield of crude TAX was obtained. The crude product was 94.5% TAX containing 5.5% RDX contamination as determined by analytical HPLC.

The major advantage of this method is the ease of controlling the exotherm. Furthermore, the initial mixing chamber contains only a small amount of material at any one time, increasing the safety of the reaction. This process allows the rapid production of TAX, avoids the potentially dangerous exotherm, and affords TAX in adequate yield (Table 2, runs 6 and 7) and high purity ($\geq$ 90%).

The following other modifications on the reaction procedure were attempted: (1) adding a cosolvent such as trifluoroacetic acid and CH_2Cl_2, (2) saturating the TFAA with crude TAX/RDX mixture before adding TRAT, (3) running the reaction at 35°C by preheating the TFAA containing TRAT and then slowly adding 100% HNO_3 to maintain the reaction exotherm at 35°C to 40°C and (4) slowly mixing a solution of TFAA containing TRAT with 100% HNO_3 and maintaining the reaction at 35°C. All these modifications were either ineffective or detrimental to the yield and purity of TAX.

Continuous Flow

Safety and heat removal considerations indicated that the synthesis of kilogram quantities of TAX or SEX might best be conducted in a continuous system. Two continuous reactor designs, back-mixed and plug-flow, were examined for use in the synthesis of TAX. Both are characterized by a steady-state continuous flow of reactant streams into and product stream out of the reactor.

In the back-mixed design, because of "perfect" mixing, the feed entering the reactor immediately assumes the final uniform composition throughout the reactor. The exit stream has the same composition as that within the reactor, which is at final or "end conditions." The residence time in the reactor is controlled by the flow rate and volume and must be greater than the time required for completion of reaction. It must be

Table 2

SYNTHESIS OF TAX BY BACK-MIX AND PLUG-FLOW NITROLYSIS OF TRAT

Run	TRAT, g (mmole)	Average Residence time, min	Ratio of Reactants TRAT/TFAA/HNO_3, g/ml	Temp., °C	Yield, g (%)	Ratio[a] TAX:RDX	Reactor Type
1	9 (42)	4	1.4/10/2	35	Low[b]	100:trace	Back-mix
2	3 (14)	44	1.8/13/2	35	0.83 (28)	87:13	Back-mix
3	4 (19)	17	1.4/10/2	45	2.2 (55)	85:15	Back-mix
4	14 (66)	16	1.4/10/2	40	5.7 (41)	80:20	Back-mix
5	14 (67)	15	1.4/10/4	30	-b-	Trace:100	Back-mix
6[c]	7.2 (34)	15	1.4/5/2	30	4.3 (60-70)[d]	94:6	Plug-flow
7	27 (128)	15	1.4/5/2	25	17.1 (63)	94:6	Plug-flow

[a] Composition determined by proton NMR or analytical HPLC.

[b] Not determined.

[c] Mixing chamber exploded at the end of the reaction.

[d] 60% is the minimum conversion based on material isolated.

remembered that reaction is taking place at end conditions and that concentration of reactants will be lower than the average concentration of reactants in a batch reactor. Consequently, reaction time required in a back-mixed reactor may be longer than for a batch reactor.

The plug-flow reactor more nearly approaches conditions in a batch reactor. This reactor type assumes complete mixing in the radial direction with no diffusion in the flow direction, i.e., no back-mixing. Composition varies along the flow path as it would vary with time in a batch reactor. The residence time in the reactor is adjusted by flow rate, i.e., the length and diameter of tubing, to correspond to the time required for completion of reaction.

<u>Back-mixed Reactor</u>. Yields using a back-mixed reactor were generally lower (runs 1, 2, 3, 4, 5 in Table 2) than those obtained by the batch method (Table 1) using similar reaction times. This indicates that the reaction is slower at the lower steady-state concentration of reactants in the back-mixed reactor than in the batch reactor. As might be expected, a high selectivity to TAX (∿100%) can be achieved by a short residence time (4 min) but at the expense of a low conversion (run 1, Table 2). Run 2 was conducted at a longer residence time (44 min), but conversion comparisons may not be valid because pump malfunction caused the actual reagent ratio to differ from the calculated ratio. When the ratio of HNO_3/TRAT was increased in run 5, RDX was the only isolated product.

<u>Plug-Flow Reactor</u>. The batch experiments showed that a ratio of 1.4 g TRAT/5 ml TFAA/2 ml HNO_3 improved selectivity to TAX. These conditions were used in a plug-flow reactor (runs 6 and 7, Table 2). The experiments resulted in ∿65% conversion with 94% selectivity to TAX in a ∿15-min residence time.

An otherwise well-behaved and easily controlled run 6 ended with an unexplained explosion in the mixing chamber of the reactor during shutdown. Approximately 1.2 g of TRAT/TAX/RDX was involved in the explosion. Only the mixing chamber portion of the reactor was lost during the explosion. The coil portion of the reactor and its contents (∿4.8 g

TRAT/TAX/RDX) were untouched. The experiment was successfully repeated in run 7 without any explosion on 27 g of TRAT, affording 17.1 g of 90% TAX.

Prototype Reactor Conditions. In run 7, ∿10 g TAX/hr was synthesized in a 3.6-ft length of 1/4-in.-O.D. glass and FEP tubing, immersed in water. The internal volume of the coil was 5.6 ml/ft, or 20 ml total. The total volumetric feed rate was ∿1.33 ml/min, corresponding to a nominal reactant residence time of 15 min, neglecting gas evolution.

Evolution of gas, presumably NO_x, was rapid in the first few inches of the coil and virtually negligible in the final 2-3 ft. The gas evolution rate was estimated to be no more than ∿1 ml/sec. At the low liquid feed rate used, nearly all the NO_x was evolved within the initial downflow part of the coil and traveled counterflow to the liquid phase, back to the mixing vessel, where it was vented to the atmosphere. Consequently, most of the coil remained full of liquid, and the actual residence time was close to that computed on the basis of negligible gas evolution.

Assumptions for Scale-Up. The contemplated scale-up ratio is ∿40:1. Because the reaction is highly exothermic, it is desirable to maintain a high surface-to-volume ratio as in the prototype reactor, at least during mixing and the initial part of reaction. This means that the 1/4-in. FEP tube size should be retained on scale-up, if possible.

The scaled-up feed rates correspond to a linear velocity of ∿2 in./sec if gas evolution is neglected and up to ∿8 ft/sec if gas evolution is included. These are tolerable velocities, but they are too high to permit counterflow separation of the NO_x. Consequently, the scaled-up reactor should consist of two stages, with efficient removal of gas after the first stage.

As shown in Figure 1, the first stage can consist of 100 ft of 1/4-in. FEP tubing, which provide adequate heat transfer to control the very rapid gas evolving reactions, but will provide essentially negligible residence time (<1 min for the slower nitrolysis reaction. The second or

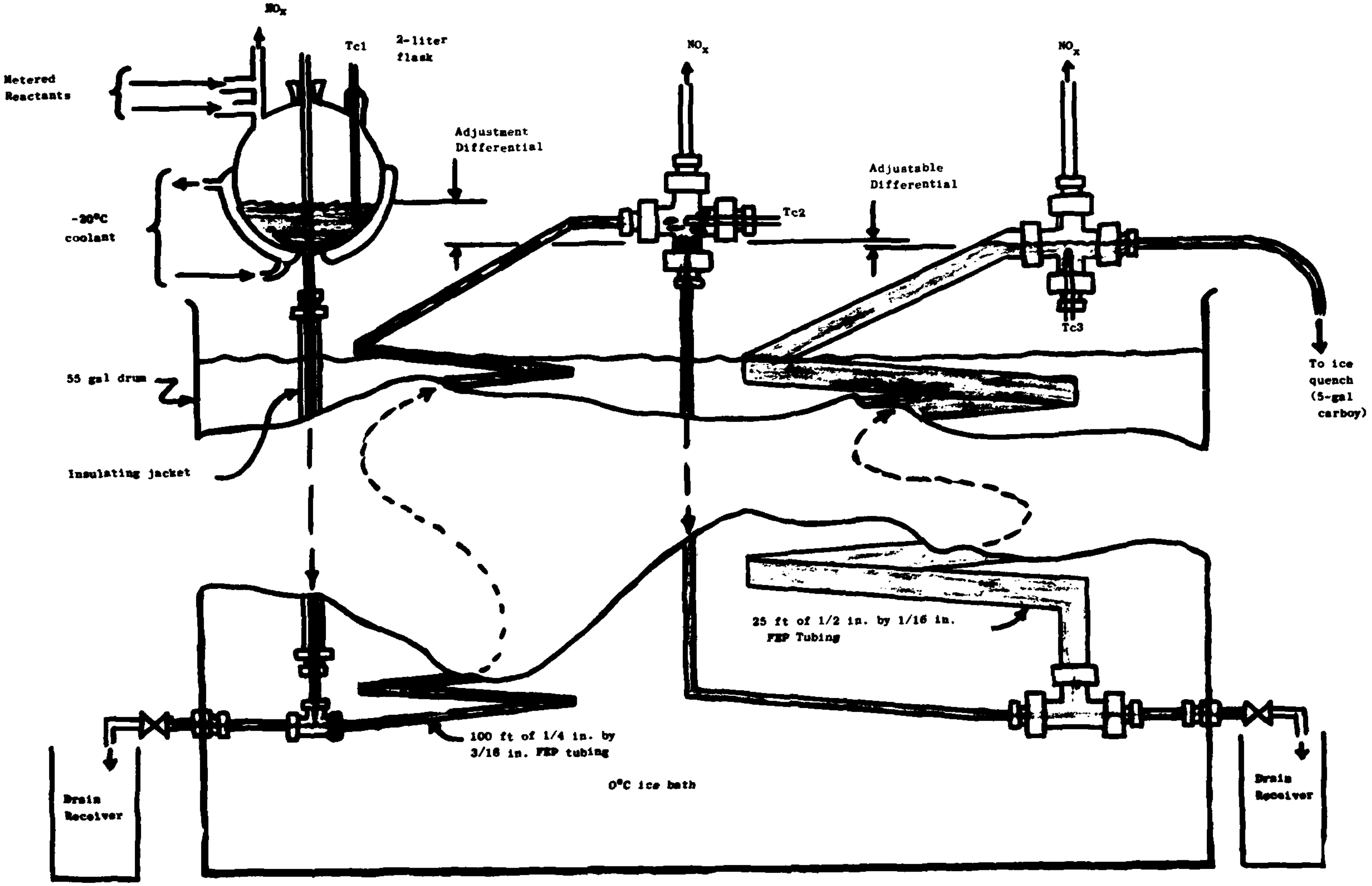

FIGURE 1 SCHEMATIC OF REACTOR FOR TAX SYNTHESIS SCALE-UP (TO ~400 G TAX/HR) AT ~60% YIELD

"finishing" stage can consist of 25 ft of 1/2-in. FEP tubing, which will provide about 15 min residence time for the liquid phase (assumed essentially gas-free) to permit the nitrolysis reaction to go to optimum completion.

Special provisions may be necessary to ensure that the downcomer preceding the first stage becomes and remains full of liquid, to make the rest of the system operate in smooth gravity flow. We assume that maintaining low enough temperature (e.g., -20°C) in the mixer vessel and in the (jacketed) downcomer will effectively inhibit the reactions responsible for gas evolution, until the reactants reach the upflow portion of the first stage. We also assume that the downcomer preceding the second stage will remain gas-free without special provisions.

Purification of TAX

The crude TAX obtained by the method described above contains 5% to 30% RDX as the sole contaminant. The first method used to obtain TAX of 98% purity was crystallization. The TAX/RDX mixture was recrystallized from a number of solvents (Table 3); however, despite the solvent used, the TAX remained contaminated with 7% to 20% RDX as determined by analytical HPLC. We also attempted to remove the RDX contamination by treating the crude TAX/RDX mixture with various concentrations of H_2SO_4, filtering insoluble materials, and neutralizing and precipitating the product by cooling; however, the TAX remained contaminated with approximately 10% RDX as determined by proton NMR and TLC on silica gel. A TAX:RDX ratio of approximately 90:10 seems to form a eutectic mixture that cannot be purified further by repeated recrystallization. Also, material losses on recrystallization are 30%-60%. Therefore, recrystallization appears to be inappropriate for the purification of TAX contaminated with RDX.

The failure of recrystallization for the purification of TAX prompted an examination of various chromatographic techniques. Effective separation of TAX containing up to 20% RDX was accomplished with a 1:1 mixture of nitromethane/dichloromethane, a 1:1 mixture of ethyl acetate/ dichloromethane, and a 2:1 mixture of acetone/petroleum-ether (30°-60°C)

Table 3

RECRYSTALLIZATION OF TAX[a]

Solvent	Yield, First Crop (Second Crop), g	Total Yield, g	% RDX Contamination[b] (% RDX Second Crop)
Acetonitrile	0.60 (0.05)	0.65	13.63 (16.00)
Nitromethane	0.30 (0.08)	0.38	10.62 (21.59)
Acetone	0.40 (0.15)	0.55	10.56 (29.38)
Tetrahydrofuran	0.40	0.40	8.74 (7.68)
Acetic acid	0.55 (0.10)	0.65	17.03 (22.27)
Trifluoroacetic acid	Insoluble	--	--
Methanol	0.33 (0.37)	0.70	14.28 (27.21)
Ethanol	0.70	0.70	17.94
Isopropyl alcohol (IPA)	0.57 (0.09)	0.66	20.27 (26.06)

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[a] All recrystallizations were done on 1 g of TAX previously crystallized from IPA. All samples contained ∿20% RDX initially.

[b] % contamination determined by analytical HPLC.

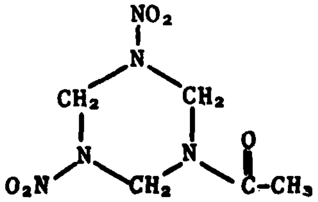
eluent. However, the low solubility of the TAX/RDX mixture in the last two solvent systems makes them unsuitable for chromatographic separations. Effective separation of TAX and RDX was accomplished on a silica gel open column using a 1:1 mixture of nitromethane/dichloromethane as eluent. This method gave essentially quantitative recovery of TAX (99.9+% by analytical HPLC). The large amounts of solvents required to dissolve the crude TAX/RDX mixture precluded the use of preparative HPLC as a method for effective purification. However, we have demonstrated that large quantities of TAX can be purified by open column chromatographic methods. This method of purification, although time consuming, has three major advantages: (1) the more expensive eluent component, nitromethane, can be recycled by distillation, (2) the silica gel can be used without regeneration because the only other contaminant, RDX, is eluted first, and (3) the amount of nitromethane: dichloromethane eluent required to dissolve the crude TAX (approximately 10 to 15 ml/g does not interfere with the chromatographic separation.

Finally, attempts were made to separate TAX and RDX by centrifugation. A 1.0-g sample of crude TAX (measured density 1.665 for pure TAX) containing approximately 20% RDX was sonicated in a saturated $ZnCl_2$ solution (density 1.75) for 30 min. The resulting solution was centrifuged for 15 min. No precipitate was observed, indicating that the RDX (measured density of 1.80) co-crystallized with the TAX. This co-crystallization also explains why recrystallization and extraction purification methods fail. The only effective purification of TAX is by open column chromatography using a 1:1 nitromethane/dichloromethane eluent mixture.

Characterization of TAX

TAX appears sufficiently stable in normal nitrolysis media to exist as a contaminant in RDX/HMX manufacturing process. The characteristics of TAX are as follows:

Structural Formula:



Empirical Formula: $C_5H_9N_5O_5$.

Elemental Analysis: Calculated: C, 27.39; H, 4.11; N, 31.96.

Found: C, 27,45, 27.40; H, 4.14, 4.16; N, 31.75, 31.87.

Melting Point: 158°-159°C.

Molecular Weight: 219 (calculated).

Solubility: Soluble in acetone, acetonitrile, methanol, ethanol, and nitromethane. Insoluble in trifluoroacetic acid.

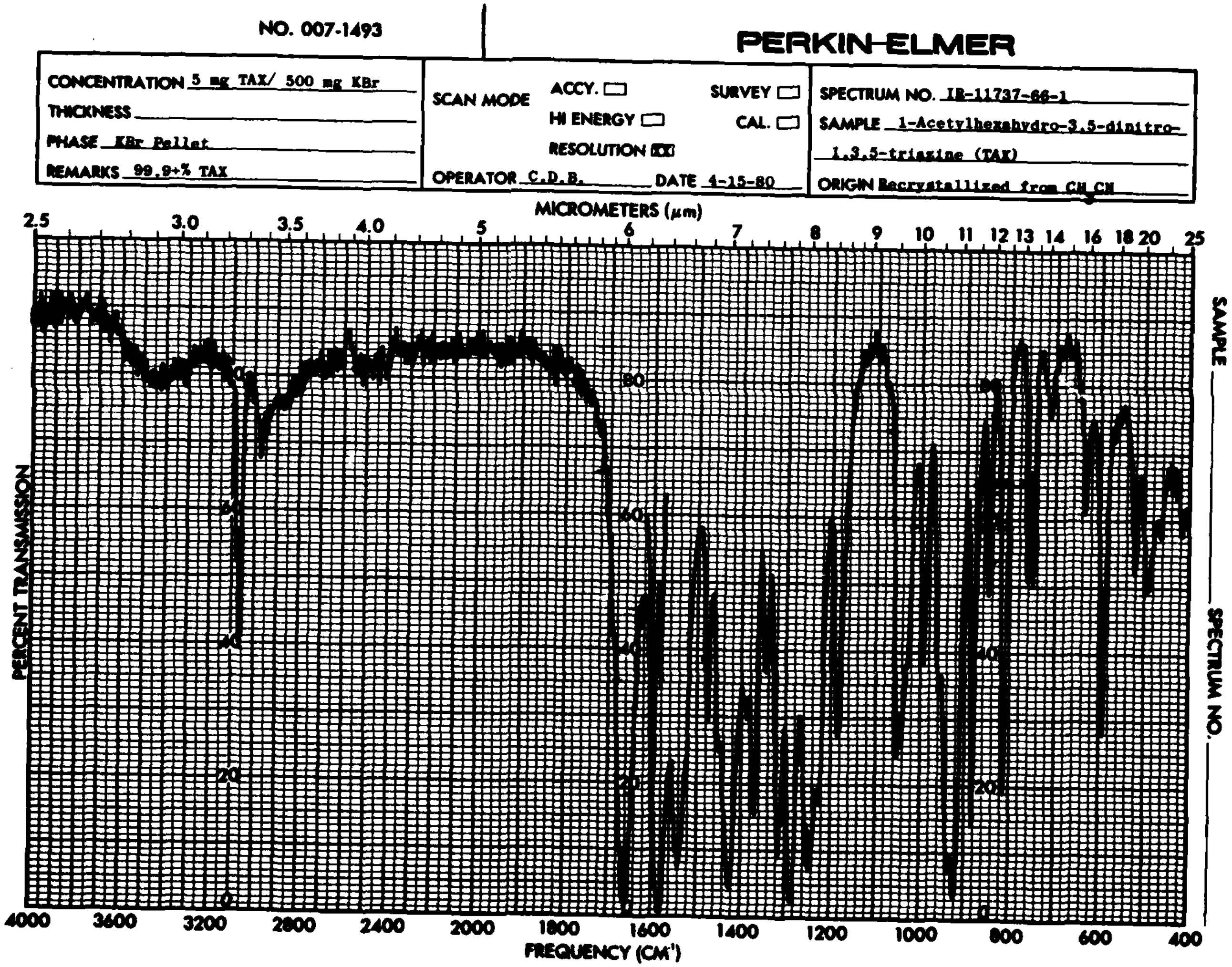
Impact Sensitivity (drop weight test): Greater than 300 kg-cm compared with 134 kg-cm for pure RDX. TAX is insensitive to direct strong hammer blows. During our investigations TAX has not exhibited any impact sensitivity.

Infrared Spectrum: See Figure 2.

Proton NMR Spectrum: See Figure 3.

Chemical Properties: TAX is destroyed rapidly by 96% sulfuric acid.

Purity: The purity of TAX was determined by analytical HPLC using a reverse-phase system with 30/70 methanol/water eluent. An internal standard of 1,3,5-trinitrobenzene was used with $1/R_f$ values of 2.39 for RDX and 3.21 for TAX. Column chromatographed TAX contained no detectable amounts of TRAT (starting material) or RDX (major contaminant of crude reaction mixtures). Also, no other contaminants were detected by HPLC, ensuring a 99.9+% purity of material.



NO. 007-1493

PERKIN-ELMER

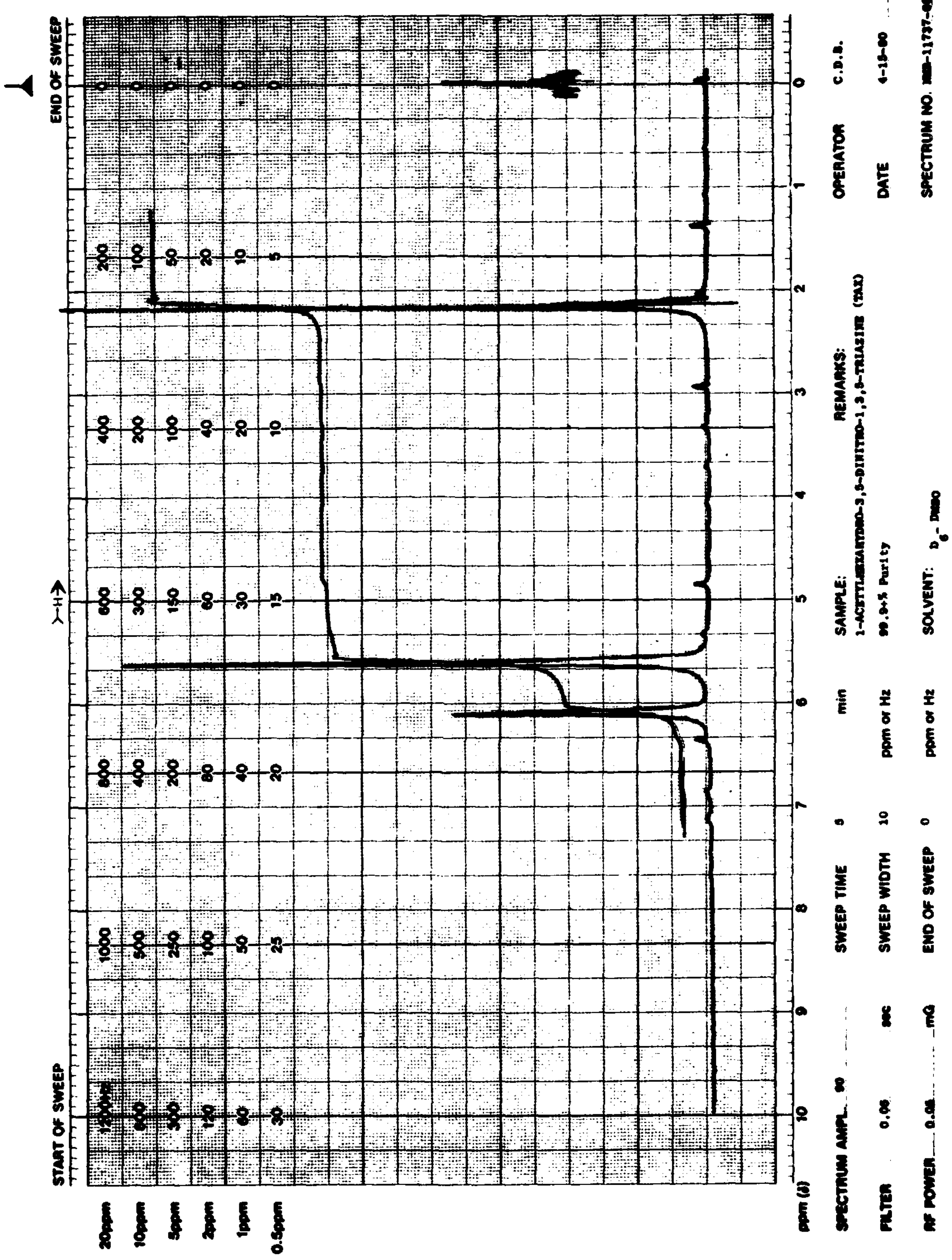
CONCENTRATION 5 mg TAX/ 500 mg KBr
THICKNESS
PHASE KBr Pellet
REMARKS 99.9+% TAX

SCAN MODE ACCY. ☐ SURVEY ☐
HI ENERGY ☐ CAL. ☐
RESOLUTION ☒
OPERATOR C.D.B. DATE 4-15-80

SPECTRUM NO. IR-11737-66-1
SAMPLE 1-Acetylhexahydro-3,5-dinitro-1,3,5-triazine (TAX)
ORIGIN Recrystallized from CH_3CN

SAMPLE
SPECTRUM NO.

FIGURE 2. INFRARED SPECTRUM



SPECTRUM AMPL. 90 SWEEP TIME 5 min SAMPLE: 1-ACETYLHEXAHYDRO-3,5-DINITRO-1,3,5-TRIAZINE (TAX) REMARKS: OPERATOR C.D.B.

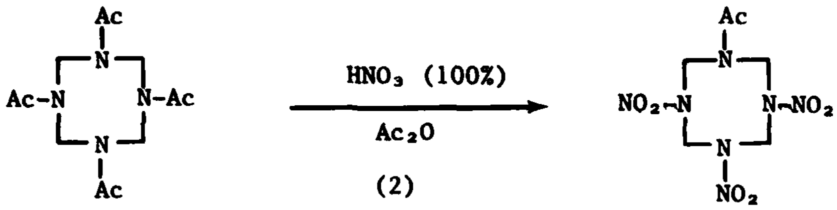
FILTER 0.05 sec SWEEP WIDTH 10 ppm or Hz 99.9+% Purity DATE 4-15-80

RF POWER 0.05 mG END OF SWEEP 0 ppm or Hz SOLVENT: D_6-DMSO SPECTRUM NO. [illegible]-11737-80-1

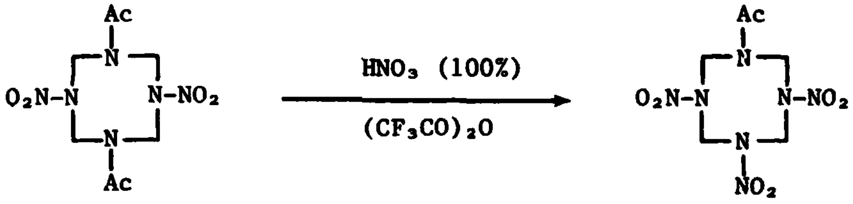
FIGURE 3. PROTON NMR SPECTRUM

PREPARATION OF SEX

SEX was prepared according to two methods of Gilbert* as shown in Equations (2) and (3).



TAT (2) SEX



DADN (3) SEX

Treatment of 2.0 g (7 mmole) of TAT with 100% nitric acid/acetic anhydride mixture yielded 93% and 40% of crude SEX in separate experiments. Based on proton NMR and TLC analysis, the crude SEX proved to be a mixture of DADN, SEX, and HMX in a ratio of approximately 0.5:1:1. The variable yield, coupled with difficult methods for the preparation of TAT and the separation of SEX from contaminants, made this route, shown in Equation (2), inadequate for large-scale preparation.

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*Private communication with Dr. E. Gilbert, Sept., 1977.

SEX was then prepared from DADN* as shown in Equation (3). Treatment of 1.5 g (5.1 mmole) of DADN with 100% nitric acid/trifluoroacetic anhydride mixtures consistently yielded 60% to 75% of crude SEX, as listed in Table 4. The reaction between DADN and the nitrolyzing medium, HNO_3 (100%)/TFAA, was modified slightly from that followed in the preparation of TAX. The DADN was found to be insoluble in TFAA and had to be dissolved in the nitric acid before mixing. Furthermore, no exotherm was observed when the DADN and the nitrolyzing medium were allowed to stand at room temperature for prolonged periods, unlike that observed during the preparation of TAX.

The synthesis, although successful, had two serious drawbacks: (1) the amount of TFAA used in the originally designed reaction procedure represented a substantial cost, making the preparation of 4 kg quantities of SEX prohibitively expensive, and (2) the crude SEX was contaminated with both HMX and DADN, which could not be removed by physical separation methods such as column chromatography, recrystallization, or extraction.

TFAA Cost

The quantities of TFAA required for the preparation of 4 kg of SEX, as shown in Table 4, runs 1 through 5, represent a substantial cost (at $15/pound). We found that 1 to 3 equivalents of TFAA (relative to the amount of DADN used) had little effect on the yield or purity of SEX (see runs 6 through 10, Table 4). Since the reaction conditions require that DADN dissolved in HNO_3 (100%) before mixing with the anhydride, we see no need to use greater than 2 equivalents of TFAA for the reaction. Thus, the conditions we have developed for the preparation of a 4 kg quantity of SEX offers a substantial savings in TFAA cost over the initial process.

Purification of SEX

The crude SEX obtained by the method described above contained a minimum of 50% contamination of DADN, HMX, or both in variable amounts (Table 4). The first method used to obtain SEX of $\geq$98% purity was

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*E. E. Gilbert, et al., "Alternative Processes for HMX Manufacture", Technical Report, ARLCD-TR-78008, Oct. 1979.

Table 4

SYNTHESIS OF SEX BY NITROLYSIS OF DADN IN HNO_3 (100%)/TFAA

Run	DADN g (mmole)	N_2O_5, eq. (ml TFAA)	Time, min	Temp., °C	Yield, g (%)	Percent Composition[a]		
						DADN	SEX	HMX
1	1.5 (5.1)	25 (18)	45	25	1.10 (73.8)	40	40	20
2	1.5 (5.1)	25 (18)	90	25	1.13 (75.8)	20	40	40
3	1.5 (5.1)	25 (18)	30	33	0.90 (60.4)	20	60	20
			45	33		Trace	70	30
4	1.5 (5.1)	12.5 (8.8)	15	38	0.95 (63.8)	20	60	20
			30	38			50	50
			45	38			60	40
5	1.5 (5.1)	25 (18)	15	5		100	-	-
			30	5	1.45 (97.0)	100	-	-
			45	5		100	-	-
			90	5		95	Trace	Trace
6	1.5 (5.1)	2 (1.4)	10	35		100	-	-
			20	35		-	-	-
			30	35	1.14 (75.0)	-	-	-
			40	35		-	-	-
			50	33		75	25	-
7	1.5 (5.1)	2 (1.4)	50	36		75	25	-
			80	35	1.04 (69.0)	48	46	6
			110	35		37	45	18
			140	35		13	52	35
8	1.5 (5.1)	3 (2.1)	30	34		-	-	-
			60	34		59	33	7
			120	34	0.94 (62.0)	31	49	21
			150	35		18	55	27
			180	34		11	56	28
9	1.5 (5.1)	1 (0.7)	80	33		65	33	Trace
			110	33		-	-	-
			140	35	0.89 (60.0)	35	48	17
			170	35		22	56	22
			230	33		14	51	32
10	1.5 (5.1)	2 (1.4)	80	34	1.1 (74.0)	50	50	Trace
11	7.5 (25.5)	25 (88)	45	36	6.35 (83.0)	15	53	32
12	7.5 (25.5)	2 (7.0)	80	35	6.0 (80.0)	38	51	11

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[a] Determined by proton NMR.

crystallization. The DADN/SEX/HMX mixture were recrystallized from a number of polar solvents such as nitromethane, acetonitrile, and acetone. However, despite the solvent used, the SEX remained a mixture of the three components with little change in composition. In addition to the lack of separation by crystallization, the amounts of solvent required to dissolve the mixture of compounds make recrystallization inappropriate for the purification of SEX.

The failure of recrystallization for the purification of SEX prompted an examination of various chromatographic techniques. Effective separation of the three components was achieved by TLC on silica gel, using a 1:1 mixture of nitromethane/dichloromethane or ethyl acetate/dichloromethane as eluent. Also, satisfactory separation was achieved using a 2:1 mixture of acetone/petroleum ether (30°-60°C) as eluent. The low solubility of the DADN/SEX/HMX mixture in solvent systems which gave chromatographic separation on TLC made purification of SEX on a large scale by gravity column chromatography unlikely.

The low solubility of the crude SEX indicated that purification might be achieved by soxhlet extraction. Extraction with a variety of solvents on crude DADN/SEX/HMX mixtures, as listed in Table 5, showed that minor improvements could be made in the purity of SEX. Based on the results shown in Table 5, ethyl acetate was selected as the solvent for partial purification of SEX. It was evident (Table 5, runs 3, 8, 9, and 10) that HMX and SEX can be partially removed from the crude reaction mixture.

The problem of HMX contamination of the extracted SEX can be minimized by running the initial reaction for only a short time (see run 10, Table 4). Ethyl acetate extraction of a mixture containing predominately DADN and SEX (run 10, Table 5) indicates that the purity of SEX can be increased by approximately 30%. Two major drawbacks still exist: (1) the SEX is still contaminated by approximately 20% to 25% DADN, and (2) the recovery of SEX is very low, approximately 20% to 40%. Although the remaining DADN/SEX mixture can be recycled, this possibility

Table 5

SOXHLET EXTRACTION OF CRUDE DADN/SEX/HMX/MIXTURES

Run No.	Solvent, ml	Weight Extracted, g (%)	Time, hr	Ratio of Products Extraction (Residue)[a]		
				DADN	SEX	HMX
1	Acetone,[b] 150	0.84 (84)	16	40	40	20
2	Methylethyl ketone,[b] 150	0.51 (51)	16	30	60	10
3	Ethyl acetate,[b] 150	0.21 (21)	16	0	28	72
4	Tetrahydrofuran,[c] 130	0.26 (52)	15	Trace	Trace	100
				(14)	(68)	(18)
5	1,2-Dichloroethane,[c] 200	0.07 (14)	15	(4)	(72)	(24)
6	Dioxane,[c] 200	0.22 (44)	15	(20)	(64)	(16)
7	Ethanol,[c] 130	0.00 (-)	15	-	-	-
8	Ethyl acetate,[c] 150	0.13 (13)	2	-	-	100
		0.17 (17)	4	-	Trace	100
		0.30 (30)	8	-	50	50
		0.44 (44)	27	Trace	50	50
				(21)	(65)	(14)
9	Ethyl acetate,[d] 250	1.04 (33)	48	Trace	50	50
10	Ethyl acetate,[e] 250	0.19 (19)	18	17	83	Trace
	250	0.10 (29)	36	24	76	Trace

---

[a] Determined by proton NMR.

[b] The initial 1.0 g of mixture consisted of a 50/33/17 ratio of DADN/SEX/HMX as determined by proton NMR.

[c] The initial 0.5 to 1.0 g of mixture consisted of a 8/52/40 ratio of DADN/SEX/HMX as determined by proton NMR.

[d] The initial 3.0 g of mixture consisted of a 15/60/25 ratio of DADN/SEX/HMX as determined by proton NMR.

[e] The initial 1.0 g of mixture consisted of a 60/40/trace ratio of DADN/SEX/HMX as determined by proton NMR.

is somewhat tenuous because HMX may form from the remaining unextracted SEX. The extraction of a DADN/SEX/HMX mixture with ethyl acetate will preferentially extract HMX, thus introducing this undesired contaminant. These results indicate that the highest purity SEX to be obtained by this procedure is approximately 80%.

It is postulated that co-crystallization of SEX and DADN precludes further purification of SEX by extraction with ethyl acetate. Furthermore, the co-crystallization of the three components DADN/SEX/HMX precludes the use of centrifugation as a method of separation, similar to the results observed in the TAX case.

EXPERIMENTAL PROCEDURES

1,3,5-Triacetylhexahydro-1,3,5-Triazine (TRAT)[*]

Hexamine (10 g, 72 mmole) was added at room temperature with stirring to acetic anhydride (41 g, 0.4 mole). A mild exotherm raised the temperature to 35°C, after which the mixture was heated for 2/hr at 98°C. The solution was cooled to 5°C, 200 ml of water was added, and the mixture was stirred for 30 min. The solution was then reduced to a viscous yellow liquid by vacuum distillation. Water (25 ml) was added, and the mixture was cooled and stirred to induce precipitation. The solid product was filtered and dried *in vacuo* over sodium hydroxide pellets, yielding 8.6 g (59.7%) of white crystalline TRAT, m.p. 91°-94°C (literature m.p., 93°-96°C). A tenfold increase in the amount of hexamine (100 g, 0.27 mole) afforded 107 g (74.7%) of TRAT, m.p. 92°-94°C.

1-Acetylhexahydro-3,5-Dinitro-1,3,5-Triazine (TAX)

CAUTION: During our investigations on the preparation of TAX, two unexplained detonations occurred with no forewarning. Injury to personnel was avoided because adequate safety measures were in force at the time of the explosions.

Batch Preparation of TAX. The following preparative procedure, a modification of that described by Gilbert et al.,[*] was found to be superior to those described in the literature. TRAT (1.4 g, 7.0 mmole) and trifluoroacetic anhydride (7.6 g, 36.5 mmole) were mixed at 15°C in a flask equipped with a magnetic stirrer, dropping funnel, and external cooling bath. Nitric acid (3.0 g of 100% acid, 48 mmole) was added dropwise with stirring and cooling at 15°-20°C. The cooling bath was

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[*] M. Warman, V. I. Siele and E. E. Gilbert, J. Heterocyclic Chem., 10, 97 (1973).

E. E. Gilbert, J. R. Leccacorvi and M. Warman, Industrial and Laboratory Nitrations," ACS Symposium Series 22, R. F. Gould, Ed., Washington, D.C., 1976, p. 337.

removed, and stirring was continued for 15 min. The solution was then poured into 100 ml of ice water. The white precipitate was filtered and dried in vacuo over P_2O_5 affording 0.95 g (58% yield) of crude TAX. HPLC analysis of the crude TAX indicated a 94% composition of TAX with only 6% RDX as the major contaminant.

Plug-Flow Preparation of TAX. For this preparation, we used a four-necked, 35 ml flask equipped with a mechanical stirrer, thermometer, condenser, two inlet tubes, and an overflow outlet located approximately 1.2 in. from the bottom of the flask. The apparatus was cooled in an ice/water bath, during which time 27 g of TRAT (0.12 mole) dissolved in 144 g of trifluoroacetic anhydride was added at a rate of 1 ml/min. by using a constant addition syringe. Simultaneously 100% HNO_3 was introduced through the other inlet at a rate of 0.33 ml/min. The resulting mixture was stirred vigorously and constantly overflowed into a 3.6-ft length of 1/4-in-O.D. glass and FEP tubing immersed in water. The total volumetric feed rate of approximately 1.33 ml/min., corresponded to a nominal reaction residence time of 15 minutes in the FEP tubing, neglecting gas evolution. The discharge from the FEP tubing was immediately quenched into an ice/water bath, precipitating the crude TAX. This material was then filtered, washed with several small portions of ice/water, and dried in vacuo over P_2O_5, affording 17.1 g (63%) TAX.

The material composition of the crude TAX as determined by analytical HPLC was 90% TAX, 6.4% RDX, and 3.4% TRAT.

Purification of TAX by Open Column Chromatography. A column packed with 400 g of 90-200 mesh silica gel was charged with 8.4 g of crude TAX dissolved in 35 ml of a 1:1 mixture of nitromethane:dichloromethane. The column was eluted with the same solvent mixture, and each fraction (75-ml portions) was examined by TLC. Fractions containing like components were combined and concentrated. The first 500 ml of effluent yielded 1.9 g of RDX upon concentration. After approximately 100 ml of solvent containing no material, the major component, 6.41 g of TAX (essentially quantitative recovery of material), eluted with the next

600 ml of solvent. Analytical HPLC showed this material to be greater than 99.9% TAX.

Anal. Calcd. for $C_5H_9N_5O_5$: C, 27.39, H, 4.11; N, 31.96.
Found: C, 27.45, 27.40; H, 4.14, 4.16; N, 31.75, 31.87.

1-Acetyloctahydro-3,5,7-Trinitro-1,3,5,7-Tetrazocine (SEX)

DADN (7.5 g, 26 mmole) was dissolved in 50 ml of 100% HNO_3 at 20°C. With cooling (ice/water bath), 7 ml of trifluoroacetic anhydride was added dropwise such that the temperature of the mixture remained between 15° and 20°C. At the end of addition, the flask was placed in a water bath preheated to 35°C and stirred for 80 min at this temperature. The mixture was then poured into ice/water and stirred for 30 min, which precipitated crude SEX. The crude SEX was filtered, washed with water, and dried over P_2O_5 *in vacuo*, yielding 6.5 g (80%) crude SEX. Proton NMR analysis of the product indicated the following composition: 38% DADN, 51% SEX, 11% HMX. To date purification of this mixture has remained inadequate.

BIBLIOGRAPHY

(1) RFP # DAMD17-79-Q-9029, "Feasibility Studies on Synthesis of Two Chemicals in Multigram Quantities, Sept. 1979, p. 18.

(2) E. E. Gilbert, J. R. Leccacorvi and M. Warman, "Industrial and Laboratory Nitrations," ACS Symposium Series 22, R. F. Gould, Ed., Washington, D.C., 1976, p. 337.

(3) E. E. Gilbert, et al., "Alternative Processes for HMX Manufacture", Technical Report ARLCD-TR-78008, AD-E400 362, Oct. 1979.

(4) M. Warman, V. I. Siele and E. E. Gilbert, J. Heterocyclic Chem., 10, 97 (1973).

(5) T. M. Benziger, R. K. Rohwer and R. K. Davey, "Process Development Studies on DADN Manufacture," MIPR-5311-1029, Los Alamos Scientific Laboratory Report for April 1975-March 1976.

(6) J. A. Bell and I. Dunstan, J. Chromatog., 24, 253 (1966).

(7) J.G.L. Harthon, Acta. Chem. Scand., 15, 140 (1961).

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