Attempted Synthesis of 1,4-Dinitro[3,4-b]-[3,4-e]Difurazanopiperazine

by
John W. Fischer
Charlotte K. Lowe-Ma
Robin A. Nissan
Richard A. Hollins
and
Ronald L. Atkins
Research Department

JULY 1989

NAVAL WEAPONS CENTER
CHINA LAKE, CA 93555-6001

Approved for public release; distribution is unlimited.
Predictions are that present day propellants and explosives will not meet the demands of the future. To meet this proposed threat, there is a continuing effort at the Naval Weapons Center to synthesize new energetic materials that exceed 1,3,5-trinitro-1,3,5-triazacyclohexane (RDX) and 1,3,5,7-tetranitro-1,3,5,7-tetraaza-cyclooctane (HMX) in performance and insensitivity. As a contribution to this program, the synthesis of a promising candidate, 1,4-dinitro-[3,4-b]-[5,6-e]difurazanopiperazine, was undertaken. This report describes the various synthetic routes attempted which led to precursors of the desired target compound.

This report has been reviewed for technical accuracy by Arnold T. Nielsen and William S. Wilson.

Approved by
R. L. DERR, Head
Research Department
18 July 1989

Released for publication by
G. R. SCHIEFER
Technical Director

NWC Technical Publication 6984
The synthesis of 1,4-dinitro-[3,4-b]-[5,6-c]difurazanopiperazine (CL-X) was attempted. Condensation of the dilithio anions of N,N'-disubstituted-diaminofurazans with cyanogen oxide gave 1,4-disubstituted-[3,4-b]furazano-5,6-dioximinopiperazines. Ring closure with sodium hydroxide in ethylene glycol at 150°C for 2 hours yielded 1,4-disubstituted-[3,4-b],[5,6-e]difurazanopiperazines. Attempts to convert these precursors into CL-X is described. A successful synthesis of CL-X was not achieved.
CONTENTS

Introduction.................................................................................................................................... 3

Results and Discussion.................................................................................................................. 4

Summary ......................................................................................................................................... 20

Experimental Section.................................................................................................................... 21
  General Procedure for the Preparation of Substituted Amino Glyoximes 5 and 8 ...................... 21
  N,N'-Diisopropylidiaminoglyoxime (8a) ...................................................................................... 21
  N,N'-Dicyclohexyldiaminoglyoxime (8b) ..................................................................................... 22
  N,N'-Diisopropyl-N,N'-dibenzyldiaminoglyoxime (12a) ............................................................ 22
  N,N'-Dicyclohexyl-N,N'-dibenzyldiaminoglyoxime (12b) ............................................................. 22
  Preparation of N,N'-Diisopropyl-3,4-diaminofurazan (9a) ......................................................... 22
  Preparation of N,N'-Dibenzyl-3,4-Diaminofurazan (9c) ............................................................ 23
  Preparation of N,N'-p-Methoxybenzyl-3,4-diaminofurazan (9d) ............................................... 23
  Preparation of N,N'-Ditosyl-3,4-diaminofurazan (9e) ............................................................... 23
  Preparation of 1,4-Dibenzyl-5,6-diketofurazanopiperazine (16c) ............................................ 24
  Preparation of 1,4-Dinitroso-furazano[3,4-b][3,4-e]-furazanopiperazine (21) ......................... 24
  Preparation of 1,4-Dibenzyl-5,6-dioximinofurazanopiperazine (14c) ....................................... 24
  Preparation of 1,4-d( .................................................................................................................. 25
  Preparation of 1,4-Diisopropyl-5,6-dioximinofurazano-piperazine (14a) ............................... 25
  Preparation of 1,4-Dibenzyldifurazanopiperazine (26c) ............................................................ 25
  Preparation of 1,4-Diisopropylidifurazanopiperazine (26a) ....................................................... 26
  Preparation of 1,4-p-Methoxybenzyl-[3,4-b][3,4-e]-difurazanopiperazine (26d) ..................... 26
  Preparation of 1,4-Cyclohexylmethylene-[3,4-b][3,4-e]-difurazanopiperazine (28) ................ 26

References....................................................................................................................................... 27
INTRODUCTION

Predictions are that present day explosives and propellants will fail to meet future battlefield demands. As both aerial and ground targets become more difficult to defeat, a new generation of energetic materials will be needed. These new compounds will have to exceed 1,3,5-trinitro-1,3,5-triazacyclohexane (RDX) and 1,3,5,7-tetranitro-1,3,5,7-tetraazacyclooctane (HMX) in performance while still remaining insensitive. Energetic materials which are hazardous to handle and sensitive to external stimuli will be of little value in the dangerous battlefield environment. Because large quantities of explosives and propellants are stored and handled in the close confines of a ship, the problem of sensitivity is especially important to the Navy. In an effort to meet these requirements, we chose to investigate the synthesis of 1,4-dinitro-[3,4-b]-[3,4-e]-difurazanopiperazine (1) with the predicted properties as compared to RDX and HMX (Reference 1).

\[
\begin{array}{ccc}
\text{NO}_2 & \text{NO}_2 & \text{NO}_2 \\
\text{N} & \text{N} & \text{N} \\
\text{N} & \text{O} & \text{N} \\
\text{N} & \text{N} & \text{O} \\
\text{N} & \text{N} & \text{O} \\
\end{array}
\]

\[
\begin{array}{ccc}
\text{NO}_2 & \text{NO}_2 & \text{NO}_2 \\
\text{N} & \text{N} & \text{N} \\
\text{N} & \text{O} & \text{N} \\
\text{N} & \text{N} & \text{O} \\
\text{N} & \text{N} & \text{O} \\
\end{array}
\]

1 RDX

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>RDX</th>
<th>HMX</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (g/cc)</td>
<td>2.00</td>
<td>1.82</td>
<td>1.90</td>
</tr>
<tr>
<td>Detonation velocity (km/s)</td>
<td>9.7</td>
<td>8.75</td>
<td>9.15</td>
</tr>
<tr>
<td>Detonation pressure (Kbar)</td>
<td>450</td>
<td>390</td>
<td>393</td>
</tr>
<tr>
<td>Isp (s)</td>
<td>266</td>
<td>...</td>
<td>264</td>
</tr>
</tbody>
</table>
RESULTS AND DISCUSSION

We initially envisioned the construction of this linearly fused tricycle (1) to start with the reaction of 3,4-diaminofurazan (2) and cyanogen oxide (3) (Reference 2) to give the dioxidinofurazanopiperazine (4). Ring closure (Reference 3) utilizing sodium hydroxide in ethylene glycol at 150°C was expected to yield 5 (Scheme 1). Nitration of amine 5 would give 1. The condensation reaction of 2 and 3 failed, presumably due to the poor nucleophilic character of the electron-deficient amine nitrogens of 2 (Reference 4). An attempt to generate the dillithio anion of 2 by treatment with either n-butyl lithium or tert-butyl lithium followed by treatment with cyanogen oxide also failed to produce any of the desired condensation product 4.

The strong electron withdrawing nature of the furazan moiety greatly reduces the reactivity of the amine nitrogens. We believed that if an electron-donating alkyl group, such as isopropyl or cyclohexyl were attached, the nucleophilicity of these nitrogens would be increased. To this end (Scheme 2), we treated the appropriate amines (6a and b) (References 2 and 3), with dichloroglyoxime (7) in refluxing tetrahydrofuran (THF) giving the corresponding substituted diaminoglyoximes (8a and b) in near quantitative yields. Ring closure of 8a or b would give the activated diamino-furazans 9a and b. Compounds of type 9 would be transformed into 1 following a similar series of reactions as outlined in Scheme 1. Unfortunately, the desired dehydrative ring closure of 8 did not occur. Dioximes 8a and b failed to close to furazans 9 using a
variety of dehydrative conditions, i.e., NaOH at 150°C, dicyclohexylcarbodiimide, or P2O5. Attempts to convert 8 to furoxans (10) using potassium ferricyanide (Reference 3) also proved fruitless.

Literature reports claim successful furazan and furoxan formation of this type only when the amine nitrogens of diaminoglyoximes were fully substituted (Reference 3). No explanation was given for these results. To circumvent this problem, we attached benzyl groups to the amine nitrogens, which, after ring closure, could be removed by hydrogenolysis (Reference 5) (Scheme 3). Dichloroglyoxime (7)
was treated with the substituted amines (11a and b) in refluxing THF to yield the fully substituted diaminoglyoximes (12a and b). Ring closure to 13, employing the methods described above, again failed. The probable reason for this lack of reactivity is severe steric congestion hindering rotation about the bond between the two oxime functionalities. Before furazan or furoxan formation can occur, the oximes must achieve coplanarity. $^{13}$C and $^{1}$H NMR show a much more complicated set of signals than anticipated. In 12a the isopropyl methyls appear as a doublet of doublets and the benzyl methylenes as an AB quartet (see Experimental Section). Figure 1 shows the benzyl methylenes $^{1}$H signal at various temperatures. Even at 140°C, the signal is quite broad. If there were the necessary rotations about all bonds, all four benzyl protons would appear as a sharp singlet. The NMR data indicated that this molecule adopts a rigid
conformation which precludes rotation about the central σ bond rendering it inert to furazan or furoxan formation.


Using a shorter, although inefficient method, we were able to form 9a. Diaminofurazan (2), upon treatment with a mixture of acetone and sodium borohydride
in acetic acid (Reference 6) yielded modest amounts of N,N'-diisopropyl-3,4-diaminofurazan (9a).

\[
\begin{array}{c}
\text{H}_2\text{N} \quad \text{O} \\
\text{H}_2\text{N} \\
\end{array}
\quad \xrightarrow{\text{NaBH}_4} \\
\begin{array}{c}
\text{H} \quad \text{N} \\
\text{H} \quad \text{N} \\
\text{H} \quad \text{O} \\
\end{array}
\]

Similar reaction with cyclohexanone gave 9b but only in very low yield after extensive purification. Much to our dismay, however, direct reaction of 9a and cyanogen oxides failed to give any trace of 14a. Addition of sodium bicarbonate, sodium carbonate, or sodium hydroxide did not induce reaction. The addition of an electron-donating alkyl group did not sufficiently activate the amine nitrogens.

A new synthetic method was examined (Scheme 4). The \( \alpha \)-diketo furazano-piperazine (15) is available from the condensation of oxalic acid and 2 (Reference 7).

\[
\text{SCHEME 4}
\]

Treatment of 15 with hydroxylamine was expected to give the dioxime 4 which would then be converted to 1. Unfortunately, even under very forcing conditions, a large excess of hydroxylamine hydrochloride, base, prolonged reaction times, and elevated temperatures, no evidence of desired oxime formation was seen.

Gasco and coworkers report that 15 exists as a pair of tautomers in equilibrium (Reference 7). Under the conditions used for oxime formation, it may be
that the equilibrium shifted exclusively to the right rendering the molecule inert. If this tautomerization could be blocked by affixing an appropriate group to the piperazine nitrogens, we believed it could then be possible to form the desired oxime as outlined in Scheme 5. Amides are known to N-alkylate (Reference 8) if treated first with a sodium base followed by an alkylating agent. Alkylation of 15 was attempted by generation of the disodium salt and subsequent addition of isopropyl bromide. We chose the isopropyl group because if 16 could be converted to 17, the isopropyl appendages could then possibly be nitrolyzed off (Reference 9) to give 1. The bases tried were sodium amide, sodium bicarbonate, and sodium hydroxide. Upon acidic workup, only unreacted 15 was recovered.

We next attempted to silylate 15 using trimethylsilyl chloride and imidazole or triethylamine. If silyl enol ether (18) were treated with fluoride, N-alkylation may have been possible. No silylation was observed. In every attempt, only unreacted starting material was recovered.
We turned our attention to a new approach to 16 (Scheme 6). Diaminofurazan (2), upon treatment with benzaldehyde or p-anisaldehyde in refluxing benzene containing a catalytic amount of p-toluene sulfonic acid (Reference 10), gave the unstable imine (19), which was reduced (Reference 10) in situ with sodium borohydride to 9c and d. Using high dilution/slow addition techniques, 9c was condensed with oxalyl chloride (Reference 12) to yield the desired disubstituted diamide (16c). The benzyl group was chosen because it was seen as being more versatile than the isopropyl functionality. Whereas the isopropyl group was viewed as a nitrolyzable entity, a benzyl group was thought to be not only nitrolyzable but also removable by catalytic hydrogenation (functioning as a protecting group) eventually yielding the free amine 5. With no tautomerization possible, 16 was treated with hydroxylamine. No oxime formed. Again, using the forcing conditions discussed above, only unreacted starting material was isolated. Comparable reactions with 9a and 9d were not attempted.

After this disappointing result, a longer synthetic route was investigated (Scheme 7).
This strategy employs generation of an anion (22) to a stabilizing nitrosamine (Reference 13). The anion would then be treated with isonitrite nitrite to form the oxime (23). Protection of the oxime followed by a repeat of the base and isonitrite nitrite treatment was predicted to give the 1,2-dioxime (24). Ring closure of 24 and nitrolysis or oxidation of the nitroso groups would yield nitramine (1).

Furazanopiperazine (20) (Reference 2b and c) when treated with an excess of nitrous acid gave dinitrosopiperazine 21. We were confident that generation of the anion α to the nitrosamine functionality of 22 was accomplished using a variety of bases, i.e., lithium disopropyl amide, lithium hexamethyltrisilazide, or potassium hexamethyldisilazide (Reference 13c). However, the anion is very stable and inert to electrophilic attack by isonitrite nitrite to form oxime (23). Attempts to unmask the anion with combinations of THF, hexamethylphosphoramide (HMPA), and tetramethylenediamine (TMEDA) failed to induce the desired reaction. If THF, HMPA, TMEDA, a large excess of isonitrite nitrite, and elevated temperatures were used, the reaction mixture decomposed. 1H NMR revealed a complex set of vinylic signals which may have resulted from an E2 elimination (Reference 14) of the anion to form 25. We were unable to isolate any identifiable compounds from the reaction mixture.
Because N,N'-dibenzyl-3,4-diaminofuran (90) readily condensed with oxaly chloride, we thought it worthwhile to examine other condensation reactions more closely. Attempted reaction between 90 and cyanogen oxide to form 14c was unsuccessful. However, the synthesis of 14c was achieved when 90 was first treated with n-butyllithium in THF at 78°C followed by addition of cyanogen oxide (3). Oxime 14c was isolated in good yield as a mixture of oxime conformers. Ring closure proceeded as expected using sodium hydroxide in ethylene glycol at 150°C for 2 hours to give 20c (Scheme 6). n-BuLi was found to be the best base for the reaction.

SCHEME 6

Other bases that were tried, but which gave poor results, were sodium hydride, sodium methoxide, potassium hydride, lithium diisopropylamide, potassium hexamethyllenecarboxylate.
disilazide, sodium bicarbonate, triethyl amine, and diisopropyl ethyl amine. Generation of the dianion of 9d with n-butyl lithium followed by addition of cyanogen oxide (3) produced 14d in much lower yield than corresponding 14c. N,N'-Diisopropyl-3,4-diaminofurazan 9d was converted to 14a, but again in much lower yield than 9c. This result is most likely caused by steric repulsion of the isopropyls in the anionic condensation with 3. Note, however, that the condensation of dianions 9a and 9d were not always reproducible. The reason for these failures could not be determined.

Analogous condensations were tried with N,N'-ditosyl-3,4-diaminofurazan (9e). The tosyl group was thought to be useful because if condensation occurred to give 14e followed by dehydration to 26e, the tosyl groups could be nitrolyzed to the nitramine 1 or removed to yield the free amine 5. Ditosylate (9e) was made by addition of tosyl chloride to 2 (Reference 15) in pyridine at 0°C. The crude reaction mixture contained a mixture of tosylates. N,N'-Ditosyl-3,4-diaminofurazan was isolated only after repeated recrystallization from ethanol. Condensation of 9e with cyanogen oxide proved to be extremely difficult. A number of bases were used which resulted in decomposition of 9e. A small amount of 14e was formed when 2,2,6,6-tetramethylthiopiperadide was used. However, 14e was difficult to purify and obtain in any reasonable quantity.

A similar strategy was attempted by affixing silyl groups to 2. If a 1,4-disilyl derivative of 26 could be formed, then direct nitrilation might be accomplished by treatment with nitronium tetrafluoroborate (Reference 16). However, efforts to attach a trimethylsilyl, tert-butyldimethylsilyl, or a tert-butyldiphenylsilyl (Reference 17) group to 2 failed.

With a number of 1,4-disubstituted difurazanopiperazines in hand, we began investigating their conversion to the target nitramine 1. Because 26c was the easiest to synthesize, we chose to investigate this compound first. Difurazan 26c was seen as a protected amine. If debenzylation (Reference 5) could be achieved, the parent amine 5 could then be nitrated to the nitramine 1. Unfortunately, 26c showed no evidence of debenzylation using Pd/C in ethyl acetate, methanol, or acetic acid. Platinum oxide (PtO₂) in acetic acid was more encouraging. After 1 to 2 weeks under hydrogen at 50 psi, the parent amine 5 may have formed as evidenced by a broad singlet in the 1H
NMR spectrum at 7.0 ppm (acetone d-6). Also in the reaction mixture was a significant amount of 28. There was a competition between the desired hydrogenolysis of the benzyl groups and hydrogenation of the aromatic ring. Attempts to purify the mixture resulted in isolation of 28 and loss of 5. Using recrystallization and chromatography methods, we failed to isolate a pure sample of 5 which appeared to be labile under the conditions employed.

Because PtO₂ was not adequate, the catalyst was changed to Pd(OH)₂ in acetic acid. As before, the hydrogenolysis required a lengthy reaction period of at least 2 weeks at 50 psi of H₂. The reaction yielded a mixture of at least two different compounds which we believe to be the amine 5 and the bis-acetyl derivative 29. The ¹H NMR (acetone d-6) showed a broad singlet at 7.0 ppm for the amine and a sharp singlet at 2.0 ppm for the diacetyl methyl hydrogens. Further evidence for 29 was the infrared (IR) spectrum which showed a carbonyl absorption at 1700 cm⁻¹ (KBr) and an M⁺ at 250 in the mass spectrum (molecular weight of 29 is 250). The crude reaction mixture once again was difficult to separate. We were unable to purify the individual components. Addition of electron-donating substituents to the phenyl ring, i.e., p-methoxy (26d), or increasing the reaction temperature, failed to improve the hydrogenolysis. Efforts to attach a different electron donating group to the ring such as p-dimethylamino as outlined in Scheme 8 failed. Although the properly substituted diaminofurazan could be made, the
yield was very low after laborious purification. Another route to attach an electron-donating amine group is also shown in Scheme 9. The nitro groups of 26g attached to the phenyl ring should reduce readily with hydrogen/catalyst to amino groups (forming

![Scheme 9]

26h) which would possibly activate the ring toward hydrogenolysis. Unfortunately, as with the dimethylamino group (9f), the substituted furazan formed only in very low yield making both of these routes unviable.

Other methods of debenzylation that were attempted on 26c and d which also failed were 2,2,2-trichloroethylchloroformate/NaHCO₃ in chloroform (Reference 18), NaH₂PO₂/Pd(OH)₂ (Reference 19), ammonium formate/Pd/C (Reference 20), and photolysis (Reference 21).

The resistance to hydrogenolysis is perplexing. In an effort to gain a better understanding of this problem, an X-ray crystal structure was obtained of 26c. Suitable crystals for analysis were grown from ethyl acetate. Figure 2 shows the result. A model of 26c predicts the piperazine nitrogens to be pyramidal. However, as seen from the X-ray structure, this is not the case. With the exception of the benzene rings, the molecule is entirely planar. Clearly, the strong electron withdrawing effects of the furazan rings delocalizes the electron pairs of the piperazine nitrogens. These amide-like nitrogens no longer resemble sp³ hybridization, but rather sp², which accounts for the lack of reactivity (Reference 22).
FIGURE 2. X-Ray Structure of 26c: (a) Bond Angles and (b) Bond Lengths and Atom Numbers. Hydrogen atoms have been omitted for clarity.
Since a mixture of the amine 5 and diamide 29 was thought to be available, although in poor yield and purity, a number of nitration/nitrolysis experiments were conducted in an effort to isolate the target nitramine 1. When the crude reaction mixture of the debenzylation of 26c, which may have contained 5 and 29, was treated with 25% N\textsubscript{2}O\textsubscript{5}/HNO\textsubscript{3} at 0°C, an off-white amorphous solid resulted which detonated upon impact using a simple hammer and anvil test. The mass recovery of material was low and a pure sample of any one compound could not be obtained. Attempts to purify the mixture using chromatography (silica gel, florisil, HPLC reverse phase C-18) and recrystallization all failed. The crude amine/amide mixture was also treated with nitronium tetrafluoroborate in acetonitrile. As before, no identifiable products were isolated from the complex reaction mixture. Similar results were found when the acetate/amine mixture was treated with nitrous acid in an effort to generate the nitrosoamide (30) which might then be oxidized to the target nitramine as illustrated.

\[
\begin{align*}
5 + 29 & \xrightarrow{HNO_3} 30 \\
& \quad \rightarrow 1
\end{align*}
\]

Direct nitrolysis of 26c was also attempted. When 26c was treated with N\textsubscript{2}O\textsubscript{5}/HNO\textsubscript{3} the reaction mixture turned dark blue in color. Upon quenching with ice and neutralizing with NaHCO\textsubscript{3}, no identifiable products were found. Decomposition also occurred with 26d when treated with N\textsubscript{2}O\textsubscript{5}/HNO\textsubscript{3}.

Numerous nitrolyses were also tried on 26a. Although literature precedent exists for such transformations (Reference 9), we were unsuccessful in all attempts. Reagents which were tried under a variety of conditions were

1. 100% HNO\textsubscript{3},
2. 100% HNO\textsubscript{3}/NH\textsubscript{4}NO\textsubscript{3}/acetic anhydride, and
3. 25% N\textsubscript{2}O\textsubscript{5}/HNO\textsubscript{3}.

The only products isolated from these reactions were unreacted starting material and small amounts of the diketone 31. The reactions were quenched with water, which probably hydrolyzed 26a to 31.
Since the piperazine nitrogens of this system resemble $sp^2$ hybridization in an electron-poor environment, it was thought possible to form nitrogen anions. This was seen as a way to further derivatize 26. Using 26a as starting material, the route shown in Scheme 10 was investigated. If 26a were treated with a strong base, i.e.,

**SCHEME 10**

Alkyl lithium, we believed an $E_2$ type of elimination would occur as shown above. The resulting double N anion could then be quenched with an electrophile. Our first choice of electrophile was a chlorosilane. If an N-silyl derivative were synthesized, treatment with nitronium tetrafluoroborate (Reference 16) should yield the desired nitramine 1. Compound 26a proved to be inert to n-butyl lithium. A reaction occurred only when tert-butyl lithium was used in a ten-fold excess in THF, HMPA, and TMEDA at -78°C. Attempted silylation using trimethylsilyl chloride, tert-butyldimethylsilyl chloride, or tert-butyldimethylsilyl triflate failed to yield the desired product. We believe a reaction did take place because no starting material was recovered and the $^1H$ NMR spectrum of the crude reaction mixture exhibited the 7.0 ppm signal (acetone) which we assigned to the parent amine. Efforts to isolate the amine led to decomposition. This route was not pursued further.
Another attempt to synthesize nitramine 1 is outlined in Scheme 11. As seen here, if 26c could be oxidized to the dibenzoyl derivative 32 then two alternate pathways to 1 would be available. Either direct nitrolysis or hydrolysis followed by nitration would yield 1. Unfortunately, all oxidation attempts failed. Using pyridinium chlorochromate (Reference 23) or Jones' reagent (Reference 24) yielded only unreacted starting material.

We also attempted to generate 1 as seen in Scheme 12. Dianilinofurazan (33) (Reference 25) when treated with base followed by cyanogen oxide (3) was expected to
yield dioxime 34. Subsequent dehydrative ring closure would give difurazanopiperazine 35. This compound when oxidized with OsO4 or RuO2 should give diacid 36 which upon decarboxylation/nitrolysis would yield 1. An alternative treatment for 35 would be conversion to 37 via direct nitration. However, no condensation was observed between 33 and 3. A wide variety of bases and reaction conditions were attempted with no sign of success.

SUMMARY

This work has resulted in the synthesis of a new ring system, 1,4-disubstituted[3,4-b]-[3,4-e]difurazanopiperazine, a direct precursor to the very energetic dinitramine 1,4-dinitro[3,4-b]-[3,4-e]difurazanopiperazine. However, attempted conversion of a number of promising precursors to the highly desirable nitramine 1 was unsuccessful. Based on our results, compound 1 and its precursor diamine 5 appear to be acid-sensitive, labile substances. Similar difurazans have demonstrated acid sensitivity. The tetrinitramine 1,4,5,8-tetranitro-1,4,5,8-tetraazadifurazano-[3,4-c]-[3,4-h]decalin, 38, readily decomposes on standing in the presence of atmospheric moisture (Reference 26). This result, in addition to our work, may indicate that very electron deficient difurazans are simply too hydrolytically unstable to be of any practical use as energetic materials.
EXPERIMENTAL SECTION

Melting points were determined in capillary tubes with a Buchi 510 melting point apparatus. Infrared spectra were recorded with a Perkin-Elmer 137, 1330, or a Nicolet 7199 Fourier transform instrument. Proton and carbon magnetic resonance spectra were recorded with a Nicolet WB200 or IBM NR80 instrument. High pressure liquid chromatography (HPLC) analyses were done on a Perkin-Elmer Series 400 liquid chromatograph using C-18 reverse phase columns. Elemental analyses were done by Galbraith Laboratories of Knoxville, Tenn. Mass spectra were recorded on a Hewlett-Packard Model 5985 instrument. Exact mass spectra analyses were done by the University of California, Riverside Mass Spectroscopy Center.

GENERAL PROCEDURE FOR THE PREPARATION OF SUBSTITUTED AMINO GLYOXIMES 5 AND 8

The appropriate amine (4 eq) and dichloroglyoxime (1 eq) were mixed in THF. A thick precipitate immediately formed. The resulting slurry was refluxed for 2 hours, cooled, and the amine salts were separated by filtration. The solvent of the mother liquor was removed under reduced pressure to yield the crude substituted amino glyoximes as yellow solids which were recrystallized from ethanol/water mixtures. Properties of the four compounds synthesized are given below.

N,N'-Diisopropylaminoglyoxime (8a)

$^1$H NMR (acetone) δ 8.95 (br s, 2 H), 5.09 (d, J = 9.7 Hz, 2 H), 3.62 (m, 2 H), 1.14 (d, J = 6.4 Hz, 12 H); $^{13}$C NMR 147.7, 45.1, 24.5; IR (KBr) 3550, 3200 (br s), 2950, 1650, 1610, 1450, 1370, 1150; mp 210 to 212°C. Analysis calculated for C$_8$H$_{18}$N$_4$O$_2$: C, 47.50; H, 8.97; N, 27.71. Found: C, 47.46; H, 9.00; N, 27.45.
N,N'-Dicyclohexyldiaminoglyoxime (8b)

\(^1\)H NMR (DMSO) \(\delta\) 9.50 (s, 2 H), 5.34 (d, \(J = 9.9\) Hz, 2 H), 3.05 (br, s, 2 H), 1.75 (m, 20 H); \(^{13}\)C NMR 24.7, 24.8, 34.3, 51.0, 146.5; IR (KBr) 3300 (broad), 2900, 1630, 1475, 1425, 1140, 960, 930; mp 211°C. Analysis calculated for C\(_{22}\)H\(_{30}\)N\(_4\): C, 69.08; H, 7.91; N, 14.65. Found: C, 69.12; H, 7.88; N, 14.61.

N,N'-Diisopropyl-N,N'-dibenzyldiaminoglyoxime (12a)

\(^1\)H NMR (acetone) \(\delta\) 9.3 (br s, 2 H), 7.3 (m, 10 H), 4.38 (d, \(J_A = 15.6\), 2 H), 4.14 (d, \(J_B = 15.6, J_{AB} = 19.2, 2\) H), 3.68 (septet, \(J = 6.7, 2\) H), 1.19 (d, \(J_B = 6.7, J_{AB} = 25, 6\) H); IR (KBr) cm\(^{-1}\) 3320, 2900, 1625, 1450, 1370, 1175, 980, 935; mp 135°C. Analysis calculated for C\(_{28}\)H\(_{38}\)N\(_4\): C, 69.08; H, 7.91; N, 14.65. Found: C, 69.12; H, 7.88; N, 14.61.

N,N'-Dicyclohexyl-N,N'-dibenzyldiaminoglyoxime (12b)

\(^1\)H NMR (acetone) splitting patterns are apparent, \(\delta\) 7.93 (s, 2 H), 7.25 (m, 10 H), 4.35 (d of d, AB quartet, \(J_A = 15.5\) Hz, \(J_{AB} = 51.6\) Hz 4 H), 3.31 (m, 2 H), 1.4 (m, 20 H); IR (KBr) 3350, 3050, 2900, 1640, 1450, 1050, 940; mp 155 to 157°C. Analysis calculated for C\(_{28}\)H\(_{38}\)N\(_4\): C, 69.96; H, 8.40; N, 11.66. Found: C, 70.29; H, 8.52; N, 11.91.

PREPARATION OF N,N'-DIISOPROPYL-3,4-DIAMINOFAZAN (9a)

Sodium borohydride (15.2 g, 400 mmol) was added in portions over 1/2 hour to a stirring solution of 3,4-diaminofurazan (2.0 g, 20 mmol) in acetone (40 mL) and glacial acetic acid (120 mL) at 0°C. The resulting thick white slurry was slowly allowed to warm to ambient temperature and stirred a total of 18 hours. Water (250 mL) was added, and the clear solution was extracted with ethyl acetate (3 x 100 mL). The combined organic layers were neutralized with solid sodium bicarbonate, washed with water (100 mL), brine (100 mL), and dried (MgSO\(_4\)). Solvent was removed under reduced pressure to afford crude 9a as an oily white solid which was recrystallized from ethyl acetate/hexane (2.17 g as white needles, mp 83 to 85°C, 59% yield). \(^1\)H NMR (acetone) \(\delta\) 5.1 (br s, 2 H), 3.61 (m, 2 H), 1.19 (d, \(J = 6.4\) Hz) 12 H; \(^{13}\)C NMR 149.1, 45.8, 21.8; IR (KBr) 3300, 2950, 1600, 1575, 1370, 1175, 820. Analysis calculated for C\(_8\)H\(_{16}\)N\(_4\): C, 52.14; H, 8.77; N, 30.41. Found: C, 51.90; H, 8.72; N, 30.28.
PREPARATION OF N,N'-DIBENZYL-3,4-DIAMINOFURAZAN (9c)

3,4-Diaminofurazan, 2. (2 g, 20 mmol), benzaldehyde (4.1 mL, 40 mmol), and p-toluenesulphonic acid (10 mg) were mixed in benzene and heated at reflux under nitrogen in a Dean-Stark apparatus for 18 hours. The yellow solution was then cooled to ambient temperature and solvent was removed under reduced pressure. The oily yellow solid was dissolved in THF (100 mL) and methanol (30 mL); sodium borohydride (6 g) was carefully added over a period of 20 minutes to the stirring solution at room temperature. Once the addition was complete, the resulting mixture was stirred for 18 hours then quenched with 1 M HCl (100 mL) and extracted with ethyl acetate (3 x 50 mL). The organic layers were combined and washed with water (100 mL), saturated sodium chloride (50 mL), and dried (MgSO4). The solvent was removed under reduced pressure to yield a white oily solid which was recrystallized from ethyl acetate/hexane to afford 4.1 g of the desired material as white needles (mp 109 to 111°C, 73% yield). 1H NMR (200 MHz, CDCl3) δ 7.28 (s, 10 H), 4.31 (d, J = 5.1 Hz, 4 H) 4.13 (br s, 2 H); 13C NMR 149.8, 137.5, 128.6, 127.9, 127.7, 48.7; IR (KBr) 3370, 3300, 3027, 2921, 1620, 1594, 1495, 1253, 742, 700. Analysis calculated for C16H16N4O: C, 68.55; H, 5.75; N, 19.99. Found: C, 68.64; H, 5.78; N, 19.95.

PREPARATION OF 3,4-BIS(p-METHOXYBENZYLAMINO)-3,4-DIAMINOFURAZAN (9d)

Preparation for 9d is the same as for 9c (22% yield). 1H NMR (200 MHz, acetone d-6) δ 7.29 (d, J_A = 8.5, 4 H), 6.85 (d, J_B = 8.5, 4 H), (J_AB = 87.6), 4.6 (br s, 2 H), 4.32 (d, J = 8.5, 4 H), 3.75 (s, 6 H); 13C NMR 160.0, 150.6, 131.5, 130.1, 114.6, 55.2 48.4; IR (KBr) cm⁻¹ 3420, 3000, 2921, 2920, 1620, 1594, 1495, 1253, 742, 700. Analysis calculated for C18H20N4O2: C, 63.50; H, 5.93; N, 16.46. Found: C, 63.43; H, 6.04; N, 16.46.

PREPARATION OF N,N'-(p-TOLUenesULFONYL)-3,4-DIAMINOFURAZAN (9e)

Tosyl chloride (3.82 g, 20 mmol) in dry pyridine (20 mL) was added dropwise to a stirring solution of 3,4-diaminofurazan (1 g, 10 mmol) in dry pyridine (20 mL) at 0°C under N2, resulting in a yellow mixture which was slowly warmed to ambient temperature and stirred overnight. The yellow suspension was then poured into H2O (50 mL) and extracted into ethyl acetate (3 x 50 mL). Organic layers were combined and washed with H2O (75 mL), saturated sodium chloride (50 mL), dried (MgSO4), and solvent removed under reduced pressure to yield a yellow oil and solid which was recrystallized from 95% ethanol (3 x) to yield 610 mg of 9e (15%, mp 136 to 138°C) as white crystals.

1H NMR (acetone d-6) δ 7.5 m (AA'BB' pattern) 8 H, 5.5 (br s 2 H), 2.40 (s 6 H); 13C NMR (acetone d-6) 156.4, 147.4, 135.6, 130.7, 129.7, 21.6; IR (KBr) 3420, 3100, 2910, 1630, 1590, 1390, 1120, MS 408 (M+), 153 (100%), 91.
PREPARATION OF 1,4-DIBENZYL-5,6-DIKETO[3,4-b]FURAZANOPIPERAZINE (16c)

N,N'-Dibenzyl-3,4-diaminofurazan (100 mg, 0.4 mmol) in dry benzene (10 mL) was added via a syringe pump to a stirring solution of oxalyl chloride (0.05 mL, 0.5 mmol) and sodium bicarbonate in dry benzene (20 mL) at ambient temperature under nitrogen over 13 hours. Once the addition was complete, the resulting solution was stirred an additional 5 hours. Solvent was removed under reduced pressure. Water (10 mL) was added to the residual solid and then extracted with ethyl acetate (3 x 15 mL). The combined organic layers were washed with water (10 mL), brine (10 mL), and dried (MgSO4). Solvent was removed under reduced pressure to afford 100 mg of 16c (mp 189 to 190°C, 75% yield) as a light yellow solid which could be further purified by recrystallization from ethyl acetate/hexane. 

1H NMR (CDCl3) δ 7.6 (m, 10 H), 5.19 (s, 4 H); 13C NMR 151.7, 143.5, 133.3, 129.7, 129.0, 128.9, 48.7; IR (CHCl3) 3020, 1720, 1590, 1320, 1210, 1200, 690, 670. Analysis calculated for C18H14N4O3: C, 64.66; H, 4.22; N, 45.12. Found: C, 64.62; H, 4.21; N, 45.72.

PREPARATION-OF 1,4-DINITROSO[3,4-b]FURAZANOPIPERAZINE (21)

Concentrated HCl (4 mL) was added dropwise to a stirring solution of furazano-[3,4-b]piperazine, 20 (1.0 g, 8 mmol), and sodium nitrite (1.24 g, 18 mmol) in H2O (50 mL) at 60°C. A thick yellow solid formed, which was stirred at 60°C for 50 minutes and then cooled to 0°C for an additional 45 minutes, collected by suction filtration, and recrystallized from warm benzene to yield 1.0 g of 1,4-dinitrosofurazano[3,4-b]piperazine as yellow plates (mp 93 to 95°C, 68% yield). 1H NMR (200 MHz) in acetone d-6, broad singlet at 4.29 ppm (major conformer), two minor conformers seen as broad singlets at 5.20 and 4.49 ppm; 13C NMR (acetone d-6, major conformer) 39.28, 144.51 ppm; IR (KBr) cm⁻¹ 3000 (w), 1630 (s), 1560 (s), 1500 (s), 1400 (s), 1350 (s), 7075 (s). Analysis calculated for C4H4N6O3: C, 26.09; H, 2.19; N, 45.65. Found: C, 26.08; H, 2.25; N, 45.72.

PREPARATION OF 1,4-DIBENZYL-5,6-DIOXIMINO[3,4-b]FURAZANOPIPERAZINE (14c)

n-Butyl lithium (1.6 M in hexane, 21.6 mL, 35 mmol) was added dropwise to a stirring solution of N,N'-dibenzyl-3,4-diaminofurazan, 9c (2.42 g, 8.6 mmol), in THF (100 mL) at -78°C under nitrogen. After 1 hour, dichloroglyoxime (1.35 g, 8.6 mmol) in THF (25 mL) was added rapidly in one portion, also at -78°C. The solution immediately turned dark red orange in color. After stirring 1 hour at -78°C and 2 hours at room temperature, the dark red solution was poured onto 1 M NaH2PO4 (100 mL) and extracted into ethyl acetate (3 x 50 mL). The combined organic layers
were washed with water (100 mL), brine (100 mL), and dried (MgSO₄). Solvent was removed under reduced pressure to afford 10 as a light yellow solid which was recrystallized from warm benzene (1.3 g, 42% yield, mp 185 to 186°C). ¹H NMR (DMSO) mixture of conformers, δ 11.93 (s), 11.82 (s), 11.78 (s (very small)), 7.31 (br s), 5.29 (s), 4.98 (s); IR (KBr) 3200 br, 1650, 1600, 1490, 1440, 1360, 1060, 950, 840; Mass Spec 364 (M+), 347 (-OH), 346 (-H₂O), 91 (100%). Analysis calculated for C₁₈H₁₆N₆O₃: C, 59.33; H, 4.43; N, 23.07. Found: C, 59.35; H, 4.42; N, 23.10.

PREPARATION OF 14d

Preparation of 14d is the same as for 14c. ¹H NMR (80 MHz, acetone d₆) 2 conformers seen δ 12.0 (br s, 2 H), 7.25 (m), 6.75 (m), 5.38 (s), 4.87 (s), benzyl -CH₂-, 3.67 (s, -OCH₃); IR (KBr) cm⁻¹ 3200, 3005, 2950, 1595, 1510, 1380, 1260; mp 195 to 197°C. Exact mass (chemical ionization using isobutane) calculated, 425.1573; found, 425.1567.

PREPARATION OF 1,4-DIISOPROPYL-5,6-DIOXIMINO[3,4-b]FURAZANOPIPERAZINE (14a)

n-Butyl lithium (1.6 M in hexane, 20.3 mL, 32.6 mmol) was added dropwise to a stirring solution of N,N'-diisopropyl-3,4-diaminofurazan (17) (1.50 g, 8.2 mmol) in THF (75 mL) at -78°C under nitrogen. After 1 hour, dichloroglyoxime (1.27 g, 8.2 mmol) in THF (15 mL) was added rapidly in one portion. The solution immediately turned dark red in color. After stirring 1 hour at -78°C and 2 hours at ambient temperature, the dark red-brown solution was poured onto 1 M NaH₂PO₄ (100 mL) and extracted into ethyl acetate (3 x 50 mL). The combined organic extracts were washed with water (100 mL), brine (100 mL), and dried (MgSO₄). Solvent was removed under reduced pressure to give 18 as a dark yellow solid which was recrystallized from warm benzene (0.45 g, 20% yield, mp 151 to 153°C). ¹H NMR (acetone) δ 12.0 (br s, 2 H), 4.6 (septet, J = 6.4 Hz, 2 Hz), 1.41 (d, J = 6.4 Hz, 12 H); IR (KBr) 3200 (broad), 2900, 1650, 1600, 1560, 1450, 1370, 1040, 930, 910; exact mass calculated, 268.1284; found, 268.1277.

PREPARATION OF 1,4-DIBENZYL[3,4-b]DIFURAZANOPIPERAZINE (26c)

1,4-DibenzyI-5,6-dioximnofurazanopiperazine (14c) (1.14 g, 3.1 mmol) was added in one portion to a stirring solution of sodium hydroxide (0.12 g, 3.1 mmol) in ethylene glycol (10 mL) at 150°C. After 2 hours, the solution was cooled and water (20 mL) was added. There was an immediate formation of precipitate. After cooling to 0°C for 1 hour, 26c was collected by vacuum filtration as an off-white solid (0.60 g, 56% yield, 93% yield based on recovered starting material, mp 170 to 175°C, dec). After the mother liquor stood for 3 days, a white solid (0.46 g), starting material (14c), was recovered. ¹H NMR (acetone) δ 7.5 (m, 10 H), 5.02 (s, 4 H); ¹³C NMR
PREPARATION OF 1,4-DIISOPROPYL[3,4-b]DIFURAZANOPIPERAZINE (26a)

1,4-Diisopropyl-5,6-dioximinofurazanopiperazine (18) (0.28 g, 1.04 mmol) was added in one portion to a stirring solution of sodium hydroxide (42 mg, 1.04 mmol) in ethylene glycol (5 mL) at 150°C. After 2 hours at 150°C, the solution was cooled to ambient temperature, water (10 mL) was added, and the resulting slurry cooled to 0°C for 1 hour. 1,4-Diisopropyl difurazanopiperazine was collected by vacuum filtration as an off-white solid (190 mg, 73% yield, mp 159 to 161°C). 1H NMR (acetone) δ 4.45 (septet, J = 6.4 Hz, 2 H), 1.40 (d, J = 6.4 Hz, 12 H); 13C (acetone) 147.8, 53.2, 18.4; IR (KBr) 2900, 1625, 1590, 1370, 1050, 820; Mass Spec 250 (M), 166 (100%). Exact mass calculated, 250.1178; found, 250.1188.

PREPARATION OF 1,4-p-METHOXYBENZYL-[3,4-b]-[3,4-e]-DIFURAZANOPIPERAZINE (26d)

The preparation of 26d is the same as for 26c (70% yield). 1H NMR (80 MHz, DMSO d-6) δ 7.55 (d, J_A = 10, 4 H), 6.95 (d, J_B = 10, J_AB = 32, 4 H), 4.90 (s, 4 H), 3.70 (s, 6 H); 13C 159.0, 147.2, 129.3, 125.6, 113.8, 54.8, 50.6; IR (KBr) cm⁻¹ 3020, 2910, 1580, 1505, 1250, 1175, 1030, 810; mp 187 to 188°C. Exact mass calculated, 406.1389; found, 406.1382.

PREPARATION OF 1,4-CYCLOHEXYLMETHYLENE-[3,4-b]-[3,4-e]-DIFURAZANOPIPERAZINE (25)

1,4-Dibenzyl[3,4-b]-[3,4-e]difurazanopiperazine (26c) (230 mg, 0.7 mmol) was dissolved in glacial acetic acid (10 mL). Platinum oxide (10 mg) was added and the mixture was placed on a Parr hydrogenation apparatus at room temperature, 50 psi hydrogen pressure for 4 days. The mixture was celite filtered and partitioned between CHCl₃ (100 mL) and H₂O (30 mL). The CHCl₃ layer was neutralized with aqueous sodium bicarbonate, washed with brine (25 mL), and dried (MgSO₄). Solvent was removed under reduced pressure yielding an off white solid (175 mg), which was purified by silica gel chromatography (eluted with 30% ethyl acetate-hexane). Compound 28 was isolated as a white solid (50 mg, 20%). 1H NMR (80 MHz, CDCl₃) δ 3.71 (d, J = 7.2, 4 H), 2.2 (m, 2 H), 1.75 (m, 10 H), 1.2 (m, 10 H); 13C NMR 147.1, 54.6, 35.1, 30.5, 26.1, 25.5; IR (CH₂Cl₂) cm⁻¹ 2920, 2850, 1670, 1580, 1320, 915, 870, 835; mp 222 to 223°C. Analysis calculated for C₁₈H₂₆N₆O₂: C, 60.30; H, 7.32; N, 23.45. Found: C, 60.30; H, 7.38; N, 23.28.
REFERENCES

   (b) Naval Surface Weapons Center. Estimation of Normal Densities of Explosive  
   Compounds From Empirical Atomic Volumes, by D. A. Cichra, J. R. Holden, and C.  
   Dickinson, Silver Spring, Md., NSWC, February 1980. 39 pp. (TR79-273,  
   publication UNCLASSIFIED.)


   p. 452.  
   (1982), p. 73.

   p. 937.  


   (c) B. Loev, J. H. Musser, R. E. Brown, H. Jones, R. Kahlen, F. C. Huang, A.

   p. 1361.


   p. 3408.


21. (a) J. D. Timpa, M. G. legendre, G. W. Griffin, and P. K. Das. *Carbohydrate
   (b) N. J. Turro, C. -H. Tung, I. R. Gould, G. W. Griffin, R. L. Smith, and A.


INITIAL DISTRIBUTION

4 Naval Air Systems Command
   AIR-5004 (2)
   AIR-932 (1)
   AIR-932F (1)
10 Chief of Naval Research, Arlington (OCNR-1132, Dr. R. S. Miller)
   2 Naval Sea Systems Command (Technical Library)
   1 Commander in Chief, U. S. Pacific Fleet (Code 325)
   1 Headquarters, U. S. Marine Corps (Code RD-1, A. L. Slafkosky, Scientific Advisor)
   1 Commander, Third Fleet, San Francisco
   1 Commander, Seventh Fleet, San Francisco
   2 Naval Academy, Annapolis (Director of Research)
   1 Naval Explosive Ordnance Disposal Technology Center, Indian Head (Code D, L. Dickinson)
   2 Naval Ordnance Station, Indian Head
      Code 5253, W. G. Roger (1)
      Code 5253L, J. Moniz (1)
   1 Naval Postgraduate School, Monterey (Code 012, Dr. J. Wall, Director, Research Administration)
   8 Naval Research Laboratory
      Code 2627 (6)
      Code 6030, Dr. R. Gilardi (1)
      Code 6120, Dr. W. Moniz (1)
   1 Naval Surface Warfare Center, Indian Head (Code R16, J. Consaga)
   11 Naval Surface Warfare Center, White Oak Laboratory, Silver Spring
      Code R10, K. F. Mueller (1)
      Code R10C, L. A. Roslund (1)
      Code R10D
         H. G. Adolph (1)
         C. Bedford (1)
      Code R10E, J. M. Kelley (1)
      Code R11
         C. Gotzmer (1)
         J. M. Short (1)
      Code R13, C. Dickinson (1)
      Code R16, N. Seiden (1)
      Dr. R. Doherty (1)
      Dr. J. Holden (1)
   1 Naval War College, Newport
   1 Naval Weapons Support Center, Crane (Code 5063, Dr. H. Webster III)
   1 Naval Weapons Station, Yorktown (L. R. Rothstein)
   1 Office of Naval Technology, Arlington (Dr. E. Zimot)
   4 Army Armament Research and Development Center, Dover
      SMOCAR-LCE-C
         Dr. J. Alster (1)
         Dr. E. Gilbert (1)
         Dr. N. Slagg (1)
         Dr. G. Sollott (1)
   5 Army Ballistic Research Laboratory, Aberdeen Proving Ground
      DRCAF-IBD, A. Junasz (1)
      DRXBR-IBD
         Director (1)
         Dr. I. W. May (1)
      DRXBR-TRD
         Dr. P. Howe (1)
         J. J. Pocchio (1)

30
3 Army Research Office, Research Triangle Park  
Chemical and Biological Sciences Division  
R. Gherardelli (1)  
C. R. Husk (1)  
Engineering Division, Dr. D. Mann (1)  
1 Ballistic Missile Defense Advanced Technology Center, Huntsville (D. C. Sayles)  
1 Air Force Academy, Colorado Springs (FJSL/N, J. S. Wilkes, Jr.)  
2 Air Force Astronautics Laboratory, Edwards Air Force Base  
AFAL/DY, R. Geisler (1)  
AFAL/LKLR, Dr. F. Roberto (1)  
1 Air Force Intelligence Agency, Bolling Air Force Base (AFIA/INTAW, Maj. R. Esaw)  
2 Air Force Office of Scientific Research, Bolling Air Force Base  
Directorate of Chemical and Atmospheric Sciences  
Dr. D. L. Ball (1)  
Dr. A. J. Matuszko (1)  
12 Defense Technical Information Center, Alexandria  
1 Fluorochem, Incorporated, Azusa, CA (Dr. R. D. Chapman)