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TECHNICAL REPORT AFATL-TR-73-244

THERMOCHEMICAL EVALUATION OF ADVANCED GUN PROPELLANTS

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INTERIOR/EXTERIOR BALLISTICS BRANCH
GUNS AND ROCKETS DIVISION

DECEMBER 1973

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A theoretical, thermochemical propellant-performance computer program has been used at the Air Force Armament Laboratory to evaluate potential ingredients for advanced gun propellants. The program provides a good first approximation to propellant parameters such as impetus, flame temperature, and gas molecular weight. The program was used to evaluate the thermodynamic properties of advanced propellants containing ingredients being considered for further development. Sixteen of these ingredients with different binders were investigated and theoretical computations obtained.

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PREFACE

This technical report is based on work performed at the Air Force Armament Laboratory between January 1972 and October 1973 in support of Project 25470702.

This technical report has been reviewed and is approved.

DALE M. DAVIS
Director, Guns and Rockets Division

TABLE OF CONTENTS

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SECTION I

INTRODUCTION

After many years of dormancy, the field of gun propellants has recently attracted renewed activity. A theoretical, thermochemical propellant-performance computer program has been used at the Air Force Armament Laboratory to evaluate potential ingredients for advanced gun propellants. This thermochemical program is a modification of one used by the National Aeronautics and Space Administration Lewis Research Center (NASA Lewis) and is described in detail in Reference 1. The program provides a good first approximation to propellant parameters of interest (i.e., impetus, flame temperature, gas molecular weight, etc.).

This report discusses the thermodynamic properties of advanced propellants containing ingredients which were used or were considered for use by contractors for the Air Force Armament Laboratory. These ingredients were oxidizers or coolants and were generally high in hydrogen content. This report gives the results of theoretical computations of 16 of these ingredients with different binders.

Reference:

1. Otto K. Heiney: Theoretical Gun Propellant Thermo Chemical Evaluation, Air Force Armament Laboratory Technical Report AFATL-TR-71-11, January 1971.

SECTION II

DISCUSSION

Nitrocellulose and nitroplasticized formulations have been thoroughly evaluated for use in gun propellants. The thermochemistry of these systems is such that as the propellant energy (or impetus) is increased, the propellant flame temperature is also increased. High flame temperature is a limiting factor in the barrel life of aircraft cannon designed for high rates of fire. The present objective of the propellant effort at the Air Force Armament Laboratory is to achieve increased propellant impetus ($\geq$ 360,000 ft lb/lb), while reducing the propellant flame temperature ($<$ 2600°K).

Rocket propellant technology was used as the basis for selection of some of the ingredients considered for use in the advanced gun propellant program. A theoretical thermochemical propellant-performance computer program was used to evaluate 16 potential propellant ingredients. The validity of the program can be seen in Table 1 where the impetus values of several propellants are presented. The experimental values obtained from closed bomb studies were in good agreement with the theoretical impetus values. The potential propellant ingredients included - HNF (Hydrazine nitroformate), HMX (sym Cyclotetramethylene tetranitramine), TAMED (bis-Tetramethylammonium ethylene dinitramine), TMAN (Tetramethyl ammonium nitrate), BETN (Betaine nitrate), EDNA-EDH (Ethylene dinitramine ethylene dihydrazine), DHED (Dihydrazine ethylenedinitramine), DMED (Dimethyl ethylene dinitramine), ISO-DMED (Isomer of DMED), TAGED (Triamino guanidine ethylene dinitramine), TAGN (Triamino guanidine nitrate), Celcon (a polyacetal), PA/MVT (Petrin acrylate, 2-methyl 5-vinyl tetrazole copolymer, PE (Polyethylene), NQ (Nitroguanidine) and F-Salt (sym-Cyclotrimethylene trinitrosamine). The computer calculations were all made at an arbitrarily selected constant chamber pressure of 5,000 psia. The heats of formation used in these calculations are listed in Table 2 and were derived from a multitude of sources. There was sufficient communication between the propellant contractors and the Armament Laboratory to ensure that the calculations made at each place used comparable heats of formation and that 5,000 psia was used as the common chamber pressure. This allowed for valid comparison of data from the various contractors.

The binders which were usually evaluated with the potential ingredients were the hydrocarbons (carboxy or hydroxy terminated polybutadiene) and nitrocellulose. The candidate ingredients were either used as oxidizers or coolants and were generally high in hydrogen content. Compounds which are high in hydrogen will contribute to decreasing the mean molecular weight of the combustion products. The significance of this is seen in the following equations: 1

$$F_P = \frac{T_f}{M_W} R$$

where:

F_P is the propellant impetus in ft-lb/lb.

T_f is the flame temperature in °K.

M_W is the mean molecular weight of the combustion products.

R is the engineering gas constant, 2780 ft-lb/mole °K

The impetus may be significantly increased by keeping T_f constant while decreasing M_w, the mean molecular weight. For example, when $T_f = 2600^oK$, $M_w = 24$ will yield an impetus of 301,000 ft-lb/lb while $M_w = 18$ will yield an impetus of 401,000 ft-lb/lb.

HNF, EDNA-EDH, and DHED formulations were found to have impetuses in excess of 370,000 ft-lb/lb at flame temperatures below 2600^oK. However, the incompatibility and instability (References 2 and 3) of these ingredients with the binders studied limited their usefulness. Some formulations with TAMED, TMAN, and PA/MVT were found to yield impetus levels between 340,000 to 360,000 ft-lb/lb and flame temperatures near 2600^oK. These compounds were found to have the following limitations: TAMED and TMAN-hygroscopicity, and PA/MVT-processing difficulties. DMED propellants were developed for use as cool burning gun propellants with flame temperatures less than 2400^oK and impetus levels of 340,000 ft-lb/lb. Extremely thin propellant web thicknesses were dictated by low burning rates (Reference 3) and may limit the usefulness of DMED propellants. BETN was not pursued as a propellant ingredient since the computer calculations indicated impetus levels less than 350,000 ft-lb/lb at flame temperatures near 2600^oK. A number of formulations with HMX, ISO-DMED, TAGED, TAGN, and R-Salt as propellant ingredients were found to have impetus levels greater than 370,000 ft-lb/lb and flame temperatures less than 2600^oK; of these, HMX, ISO-DMED, and TAGN have been processed in propellants without signs of incompatibility. TAGED and R-Salt have not undergone compatibility studies yet. Although the target impetus of 360,000 ft-lb/lb and flame temperature of 2600^oK could be met with a 35/65 mixture of Celcon/HMX, the processing difficulties (Reference 4) associated with Celcon precluded its further consideration. Polyethylene did not exhibit any promising thermodynamic properties except for an NC/HMX/PE (25/65/10) formulation. However when 10% PE was used, the adhesion of NC to HMX and PE became so poor that the propellant grains broke up in gun firings[1]. None of the formulations with NC, NQ, and HMX produced the target thermodynamic objectives. It was found that in a formulation containing NC, IDP , TAGN, HMX, and NQ, substitution of NQ for TAGN reduced the impetus of the propellant without reducing the flame temperature. NQ was discarded from consideration as a propellant ingredient because there did not appear to be any advantage to its use.

The theoretical thermochemical program has been useful in screening out ingredients which were not promising and in isolating the propellant formulations which would produce thermodynamic properties meeting the program objectives.

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[1]Personal Communication between J. E. Flanagan, Rocketdyne, Canoga Park, California, and O. K. Heiney, Eglin AFB, Florida, February 1973.

References:

2. J. E. Flanagan: High Energy Gun Propellants, Air Force Armament Laboratory Technical Report AFATL-TR-72-89, May 1972.
3. E. H. Zeigler: New Compounds for Cool-Burning Gun Propellants, Air Force Armament Laboratory Technical Report AFATL-TR-73-101, April 1973.
4. H. J. McSpadden: Thermoplastic Gun Propellant, Air Force Armament Laboratory Technical Report, AFATL-TR-73-142, July 1973.

SECTION III

INGREDIENT EVALUATION

1. HNF

Hydrazine nitroformate (HNF) is an energetic material which had been evaluated in rocket propellants and discarded because of its incompatibility with other materials. Two relatively stable polymers, saturated Hydroxy terminated polybutadiene (HTPB) and Ethyl cellulose (EC) were selected for evaluation with HNF in candidate gun formulations. In the HTPB formulations, HNF levels less than 70% yielded impetus values (Table 3A) less than 300,000 ft-lb/lb. At 80% HNF, the impetus was an attractive 394,000 ft-lb/lb with a flame temperature of 2670°K. It appeared that an impetus of >370,000 ft-lb/lb and a flame temperature of <2600°K were possible with either binder. However, laboratory studies at Rocketdyne, Canoga Park, California, revealed that compatibility problems with HNF still existed, even in these two stable polymers.

2. HMX

The compound sym-Cyclotetramethylene tetranitramine (HMX) is an energetic, stable material which has been used as an oxidizer in rocket propellants and explosives. HMX was first evaluated with the hydrocarbons because of their high thermal stability. These propellants would have the added advantage of high cook-off temperatures ($\geq$ 270°C) in addition to the expected advantages of high impetus levels and low flame temperatures. The results of the computer calculations with the two hydrocarbons (Butarez, which is a carboxy-terminated polybutadiene, and Butyl rubber) are presented on Table 3B. For the preliminary screening of the propellant formulations, curing agents and other additives were neglected. In the Butarez binder, an HMX level of 85% produced an impetus of 370,000 ft-lb/lb and a flame temperature of 2540°K. At 84% HMX, the system was under-oxidized and at 86%, the flame temperature exceeded 2600°K. Because of a less favorable heat of formation, higher HMX loadings were required for the Butyl rubber system, i.e., about 87% HMX and 13% Butyl rubber vs. 85% HMX and 15% Butarez for an impetus of 370,000 ft-lb/lb. In the hydrocarbon formulations, the Butarez polymer appears more attractive thermodynamically.

The addition of HMX to nitrocellulose (NC) at either the 12.6% or 13.15% nitrogen level increases the impetus as well as the flame temperature (Table 3B). Replacement of NC (12.6) with 80% HMX increases the impetus from 347,000 to 438,000 ft-lb/lb while only increasing the flame temperature by about 800°K (from 3100° to 3900°K). Unlike the hydrocarbons, no combination of NC and HMX would produce flame temperatures below 3000°K. The mean molecular weights of the combustion products from NC/HMX systems were in the 24 to 26 range, while those from the hydrocarbon/HMX systems were in the 18 to 21 range. Theoretically, the hydrocarbon/HMX formulations are superior to those with NC/HMX.

3. AMMONIUM SALTS

Three ammonium salts, TAMED (bis-Tetramethyl-ammonium ethylene dinitramine), TMAN (Tetramethyl ammonium nitrate), and BETN (Betaine nitrate) were considered for use in NC formulations. As can be seen from Tables 3C, 3D, and 3E, the thermodynamic properties of formulations containing these three salts were quite poor until HMX levels about 40% were used. At this HMX level, impetus levels of 330,000 ft-lb/lb or less were obtained. With less than 20%

HMX, the systems were underoxidized and carbon appeared as a solid in the combustion products. At 50% HMX and 25% of each of the salts, the impetus was only slightly better than that of nitrocellulose (350,000 vs. 346,000 ft-lb/lb). After this preliminary screening, the three ammonium salts were eliminated from further consideration.

4. EDNA SALTS

Ethylene dinitramine (EDNA) was extensively investigated as a rocket propellant ingredient in the 1950's but was discarded because it contributed to low flame temperatures. The salts of this compound appeared to be ideally suited for gun propellant applications.

Ethylenedinitramine ethylenedihydrazine (EDNA-EDH) was evaluated with NC (12.6) and HMX (Table 3F). The impetus and flame temperature of the formulations with 20% NC and EDNA-EDH/HMX levels of 50/30 and 60/20 were about 380,000 ft-lb/lb and 2600°K. At 30% NC, impetus levels of 370,000 ft-lb/lb could be achieved at temperatures below 2600°K At flame temperatures of current single base propellants (3000° to 3100°K), impetus levels greater than 400,000 ft-lb/lb could be achieved. The last set of calculations on the table indicated that there was no loss in thermodynamic properties in the propellant when RDX was substituted for HMX. Although RDX is less thermally stable than HMX, it is about one third the cost of HMX. However, this lower decomposition temperature of RDX is consistent with the decomposition temperatures of NC. Further laboratory studies revealed that EDNA-EDH would not be suitable for use because of its incompatibility with nitrocellulose.

Three different binders were evaluated with Dihydrazine ethylene dinitramine (DHED) and HMX (Table 3G). In the formulations containing 14% Butarez (CTPB), DHED was considered as a coolant for the HMX. The calculations indicated that for each 5% increment of HMX which was replaced by DHED, a 90°K reduction in flame temperature was achieved. However, each increment of DHED also resulted in a decrease in impetus of about 10,000 ft-lb/lb. The formulation containing 14% CTPB, 76% HMX, and 10% DHED had the attractive thermodynamic properties of 365,000 ft-lb/lb impetus, 2440°K flame temperature, and a gas molecular weight of 18.6. DHED was considered as the oxidizer in NC (12.6) systems. At 75% DHED, the impetus of 353,000 ft-lb/lb is slightly better than that of M-10 (346,000 ft-lb/lb), but the flame temperature is significantly lower (2300°K vs. 3000°K). Replacement of 10% DHED with HMX results in an impetus of 370,000 ft-lb/lb and a flame temperature less than 2500°K. In the formulation with 25% NC (12.6), 30% HMX, and 45% DHED, an impetus of nearly 400,000 ft-lb/lb and a flame temperature of less than 3000°K is possible. Because there were indications of chemical incompatibility of DHED and NC, Ethyl cellulose (EC) was considered as an alternate binder. The thermodynamic properties of NC/EC/HMX with HMX levels as high as 50% were very poor, with impetus levels less than 295,000 ft-lb/lb. The formulations considered were all under-oxidized since carbon appeared as a solid in the combustion products. Chemical incompatibility with nitrocellulose eliminated DHED from further study.

Dimethyl ethylene dinitramine (DMED) was one of the compounds investigated for cool burning gun propellants by the Allegany Ballistic Laboratory (ABL) (Reference 2). DMED was considered as the primary oxidizer in formulations containing 20%, 25%, and 30% NC (Table 3H). With DMED concentrations of 60% to 70% and 10% HMX, impetus levels of 320,000 ft-lb/lb and flame temperatures below 2250°K were obtained. The goals of 330,000 ft-lb/lb impetus and $\leq$ 2400°K could be achieved by using HMX levels of $\geq$15% in the 20%, 25%, or 30% NC levels. Extrapolation of the data in Table 3H indicated that DMED formulations could also provide impetus level >360,000 ft-lb/lb at flame temperatures < 2600°K. The lower burning rates of DMED propellants may limit their use.

ISO-DMED, a liquid by-product obtained during the manufacture of DMED, was found by ABL to have a more favorable heat of formation than DMED (-1.06 vs. -20.11 kcal/100 gm). Computer calculations (Table 3I) verified that replacement of DMED with its isomer resulted in increasing the impetus in NC (12.6) systems. Substitution of 50% ISO-DMED for DMED yielded an increase in impetus from 326,000 to 363,000 ft-lb/lb. The impetus and flame temperature were increased from 357,000 to 384,000 ft-lb/lb and 2520° to 2950°K, respectively, when 20% of the ISO-DMED was replaced with HMX. Varying the ratios of NC (12.6)/ISO-DMED from 30/70 to 70/30 did not affect the impetus (355,000 ft-lb/lb) but did increase the flame temperature from 2333° to 2731°K. Formulations containing NC/ISO-DMED/TAGN yielded impetus levels as high as 383,000 ft-lb/lb with flame temperatures still below 2600°K. ISO-DMED appears to be an attractive ingredient worth further study.

Triamino guanidine ethylene dinitramine (TAGED) was another salt of EDNA with a high hydrogen content which appeared to have promising thermodynamic properties. Computer calculations were run on formulations where TAGED was treated first as a coolant, and then as an oxidizer (Table 3J). In a formulation with an 86% solids loading in a Butarez binder, substitution of 5% TAGED for HMX reduced the flame temperature from 2640° to 2520°K. When TAGED levels greater than 5% were used to replace HMX, the systems became underoxidized and carbon appeared as a solid in the combustion products. Apparently in the Butarez binder system, TAGED is useful only at the 5% level. In a system with 25% NC (12.6) and 75% TAGED, the high hydrogen content of TAGED contributed to a mean molecular weight of 17.7. However, it was necessary to add HMX to raise the impetus to a desirable level (360,000 ft-lb/lb). At 20% HMX, 55% TAGED, and 25% NC (12.6), an impetus of 374,000 ft-lb/lb and a flame temperature of 2520°K were possible. Some additional calculations were made with the incorporation of 5% IDP as a plasticizer. As can be seen from the data, the propellant impetus is appreciably decreased with the addition of this non-energetic plasticizer. HMX levels greater than 40% would be necessary to achieve an impetus of 370,000 ft-lb/lb. It can be seen by comparison with the DHED formulations that the thermodynamic properties of DHED in both the Butarez and NC binders are better than those of TAGED formulation. However, DHED suffers from compatibility problems. Compatibility studies have not been conducted with TAGED yet.

5. TAGN

Triamino guanidine nitrate (TAGN) was another crystalline oxidizer which appeared to show promise in gun propellant applications. The data on Table 3K indicated that no appreciable differences in performance were discernible when either the Butarez or the R-45M (hydroxy terminated polybutadiene) was used as the binder. At the 14% binder level, impetus of > 360,000 ft-lb/lb and flame temperatures. < 2600°K were possible with TAGN/HMX oxidizers where TAGN was varied between 5% and 15%. The computer calculations (Table 3K) from NC (12.6)/TAGN formulations produced some interesting results. As nitrocellulose was replaced by TAGN, the impetus was increased from 347,000 to 381,000 ft-lb/lb while the flame temperature was reduced from 3088° to 2681°K. The decrease in mean molecular weight of the combustion products can be attributed to the high hydrogen content of TAGN. The other three sets of data were from formulations at varying HMX, TAGN, and NC levels. At the 20%, 25%, and 30% NC (12.6) levels, 20% HMX was sufficient to produce impetus levels greater than 370,000 ft-lb/lb and flame temperatures less than 2600°K. The thermodynamic properties of formulations containing 10%, 20%, and 30% HMX were quite similar at all three binder levels. Besides its contribution to good thermodynamic properties, TAGN also contributes to a faster propellant burning rate.

6. Celcon

The polyacetals $(-CH_2O-)$, were proposed by the Universal Propulsion Company as an ingredient which had good thermodynamic properties in gun propellant formulations. Celcon, produced by the Celanese Corporation, was the polyacetal selected for further study. A series of calculations were made with the heat of formation (-12.7 kcal/mol) supplied by the manufacturer. The data (Table 3L) indicated that an impetus of 399,000 ft-lb/lb at a flame temperature of 2565°K was possible with an HMX loading of only 40%. However, closed bomb studies (Reference 4) by the contractor did not verify the theoretical data. Heat of combustion data supplied by the contractor indicated that the heat of formation was closer to -32 kcal/mol. The computer calculations were repeated with the revised heat of formation, and the impetus levels were quite low. These impetus levels were more in line with the experimental results. While the earlier calculations indicated that a 40% HMX loading would yield about 400,000 ft-lb/lb impetus, the second set of calculations indicated that an 80% HMX loading was necessary to achieve the same impetus. The polyacetals did not appear promising enough to pursue.

7. PA/MVT

Petrin acrylate/2-methyl 5-vinyl tetrazole copolymer (PA/MVT) had been suggested for use in gun propellants by the Army. Theoretical calculations (Table 3M) with PA/MVT as the binder and HMX as the oxidizer indicated that at a 40% HMX level, the flame temperature was almost 2600°K while the impetus was 355,000 ft-lb/lb. The flame temperature was proportionately higher at higher HMX levels. All levels of PA/MVT in NC (12.6) yielded impetus below that of NC (12.6) by itself (346,000 ft-lb/lb). This copolymer was subsequently discarded from further studies because of the inherent processing problems (i.e., rapid cure during mixing).

8. NQ

NQ (nitroguanidine) has been used as a coolant in triple base gun propellants. Its cooling effect can be seen in Table 3N where NC (12.6) can be replaced with as much as 80% NQ without affecting the propellant impetus while reducing the flame temperature from about 3100° to 2700°K. As HMX was added to the formulations in place of NQ, the impetus was increased from 346,000 to 401,000 ft-lb/lb. However, this was done at the expense of the flame temperature which was raised from 2700° to 3300°K. In NC formulations containing IDP (isodecyl pelargonate) plasticizer, TAGN, and HMX, substitution of NQ for TAGN merely reduced the propellant impetus without changing the flame temperature. These data, when compared with the data from Table 3K, indicated that TAGN was a better coolant than NQ since replacement of NQ with TAGN resulted in increased impetus while replacement of NC with NQ did not affect the impetus. NQ was discarded from further consideration because it did not offer enough of an advantage to the propellant performance.

9. PE

PE (polyethylene) was considered as an additive to decrease propellant flame temperature because its high hydrogen content $(-CH_2-)$ would contribute to lower molecular weight combustion products. When PE was substituted for 10% and 20% NC (12.6) in a single base propellant, the impetus and flame temperature (Table 3O) were substantially decreased (346,900 to 217,000 ft-lb/lb and 3100° to 1700°K). Appearance of solid carbon in the combustion products indicated that these formulations were underoxidized. When 10% HMX was replaced with PE in a 25% NC system, an impetus of 363,000 ft-lb/lb and a flame temperature of 2575°K could be obtained.

When 20% PE was used to replace HMX, severe degradation of the propellant energy could be seen in the decrease in impetus from 363,000 to 272,000 ft-lb/lb. In the cool burning gun propellant system (NC/DMED/HMX), the impetus was decreased from 341,000 to 314,000 ft-lb/lb when as little as 2% of the HMX was replaced by PE. At PE concentrations of 5% or greater, the propellants became underoxidized as indicated by the appearance of carbon in the combustion products in the theoretical calculations. The effect of PE on propellants containing R-45M/TAGN/HMX was similar to that of the NC (12.6) system, i.e., the impetus and flame temperature were significantly lowered by use of PE and the addition of as little as 5% PE was enough to cause the formulation to become underoxidized.

10. R-SALT

It was considered possible that the nitramine group (-N-NO_2) in HMX and in RDX contributed to the change in burning rate exponent at high pressures (above 5,000 psi) in propellants containing nitramines, and that the nitroso (-N-N = 0) group would not exhibit this characteristic. R-Salt (sym-Cyclotrimethylene trinitrosamine) was evaluated with Nitrocellulose and a Carbowax binder (Carbowax 4000/TMP/Isonate 136T) to determine if the thermodynamics of proposed formulations even warranted its consideration. The thermodynamic properties (Table 3P) of NC (12.6), IDP, and R-Salt (65% to 75%) appeared to be quite attractive (impetus of 380,000 ft-lb/lb and flame temperature of 2600^{o} to 2700^{o}K). At R-Salt levels greater than 75%, solid carbon appeared in the combustion products. Results from systems containing R-Salt and a Carbowax binder were disappointing. At R-Salt levels up to 84%, a fuel rich environment existed, and impetus levels were less than 340,000 ft-lb/lb.

SECTION IV

CONCLUSIONS

Recent developments in gun propellants have indicated that a major breakthrough in the state of the art of aircraft ammunition is close at hand. The theoretical computer calculations discussed in this report have been useful in screening out less promising ingredients. They have also been used to direct the area of further study in the development of advanced gun propellants. Of the 16 ingredients which were considered, six were found to show some promise for use in aircraft gun propellants. Care must be taken by the researcher to conduct compatibility and stability studies of the ingredients and polymers early in the development cycle in order to avoid the loss of time and effort in the development of propellants which could not be incorporated into the inventory. Close experimental verification of combustion efficiency must also be made to assure that the delivered impetus is as high as the level predicted from the thermochemical computations.

TABLE 1. IMPETUS OF SOME GUN PROPELLANTS

	IMPETUS, ft-lb/lb	
	Theoretical	Experimental[1]
M-10	346,000	337,000
CIL 3532	335,000	325,000
RHT-7	380,000	369,000
RGP-201	357,000	346,000
F-526	363,000	357,000

CIL 3532	Deterred NC(12.6)	Canadian Industries,Ltd
RHT-7	R-45M,TDI,TAGN and HMX	Naval Ordnance Station Indian Head MD
RGP-201	NC,IDP,TAGN and HMX	Rocketdyne, Canoga Park CA
F-526	Carbowax 4000,TMP,ISONATE 136T and HMX	Thiokol, Wasatch Division Brigham City UT

(1) Closed Bomb Data, Eglin AFB, FL

TABLE 2 HEATS OF FORMATION

Abbreviation	Ingredient	Formula	Heat of Formation, kcal/100 gm
BETN	Betaine nitrate	$C_5H_{12}N_2O_5$	- 92.33
BUTAREZ	Carboxy terminated polybutadiene	$C_{7.33}H_{11.00}O_{.08}$	- 0.04
	Butyl rubber	$C_{7.14}H_{14.29}$	- 43.00
	Carbowax binder (1)	$C_{5.16}H_{7.41}N_{0.31}O_{1.65}$	-77.36
DHED	Dihydrazine ethylene dinitramine	$C_2H_{14}N_3O_4$	- 18.69
DMED	Dimethylethylene dinitramine	$C_4H_{10}N_4O_4$	- 20.11
DPA	Diphenylamine	$C_{12}H_{11}N_1$	+ 20.94
EC	Ethylcellulose	$C_{12}H_{22}O_5$	- 86.99
ETC	Ethyl centralite	$C_{17}H_{20}N_2O$	- 12.73
EDNA-EDH	Ethylene dinitramine ethylene dihydrazine	$C_4H_{16}N_8O_4$	- 2.08
HMX	sym-Cyclotetramethylene tetranitramine	$C_4H_8N_8O_8$	+ 6.05
HNF	Hydrazinenitroformate	$C_1H_5N_5O_6$	- 9.29
HTPB(SAT)	Hydroxyterminated polybutadiene (saturated)	$C_{6.85}H_{13.2}N_{.1}O_{.2}$	- 60.00
IDP	Isodecyl pelargonate	$C_{19}H_{47}O_2$	- 70.00
ISO-DMED	Isomer of dimethylethylene dinitramine	$C_4H_{10}N_4O_4$	- 1.06

(1) Carbowax binder - Carbowax 4000/TMP/Isonate 136T

TABLE 2. CONCLUDED

Abbreviation	Ingredient	Formula	Heat of Formation kcal/100 gm
K_2SO_4	Potassium sulfate	K_2SO_4	-196.64
NC(12.6)	Nitrocellulose	$C_6H_{7.55}N_{2.45}O_{9.9}$	- 61.40
NC(13.15)	Nitrocellulose	$C_{24}H_{29.45}N_{10.55}O_{41.1}$	- 73.36
NDPA	Nitrodiphenylamine	$C_{12}H_{10}N_2O_2$	+ 13.08
NQ	Nitroguanidine	$C_1H_4N_4O_2$	- 12.12
PA/MVT	Petrin acrylate/ 2-methyl 5-vinyl tetrazole copolymer	$(C_{12}H_{17}N_7O_{11})n$	- 27.59
Celcon	Polyacetal	$\{C_1H_2O_1\}n$	- 42.4 (1) - 133.3 (2)
PE	Polyethylene	$(C_2H_4)n$	- 47.4
RDX	sym-Cyclotrimethylenetrinitramine	$C_3H_6N_6O_6$	+ 6.71
R-Salt	sym-Cyclotrimethylenetrinitrosamine	$C_3H_6N_6O_3$	+ 40.80
R-45M	Hydroxyterminated polybutadiene	$C_{7.26}H_{10.26}O_{.10}$	+ .28
TAGED	Triaminoguanidine ethylene dinitramine	$C_4H_{22}N_{16}O_4$	+ 16.76
TAGN	Triaminoguanidine nitrate	$C_1H_9N_7O_3$	- 6.89
TAMED	Tetramethyl ammonium ethylene dinitramine	$C_{10}H_{28}N_6O_4$	- 34.60
TMAN	Tetramethyl ammonium nitrate	$C_4H_{12}N_2O_3$	- 59.41

(1) As supplied by vendor
(2) As determined from heat of combustion

TABLE 3 THERMODYNAMIC PROPERTIES OF EXPERIMENTAL GUN PROPELLANTS

Ingredient	Formulation	(1) Impetus, Ft-lbs/lb	(2) T_{cv}, °K	Mean Molecular Weight
A. HNF (4)				
	HTPB(Saturated)/HNF			
	40 / 60	238,032	1679	19.61 (3)
	30 / 70	284,212	1866	18.26
	20 / 80	394,426	2670	18.83
	10 /90	457,445	3805	23.13
	ETHYL CELLULOSE/HNF			
	30 / 70	382,387	2700	19.64
	25 / 75	414,529	3110	20.86
	20 / 80	437,688	3500	22 24
B. HMX (5)				
	BUTAREZ/HMX			
	16 / 84	361,910	2464	18.93 (3)
	15 / 85	373,296	2542	18.94
	14 / 86	384,802	2641	19.10
	10 / 90	420,750	3074	20.32
	8 / 92	434,630	3290	21.05

(1) Calculated at 5,000 psia
(2) Flame temperature at constant volume
(3) Solid carbon in combustion products
(4) HNF- Hydrazine nitroformate
(5) HMX - sym-Cyclotetramethylene tetranitramine

TABLE 3. CONTINUED

Ingredient	Formulation	Impetus, Ft-lbs/lb	T_{cv}, °K	Mean Molecular Weight
	BUTYL RUBBER/HMX			
	16 / 84	341,458	2266	18.46 (1)
	14 / 86	364,090	2424	18.52
	12 / 88	388,647	2656	19.01
	NC(13.15)/K_2SO_4/NDPA/HMX			
	98 / 1 / 1 / 0	360,341	3290	25.39
	93 / 1 / 1 / 5	365,294	3329	25.34
	88 / 1 / 1 / 10	370,238	3368	25.30
	83 / 1 / 1 / 15	375,048	3405	25.25
	78 / 1 / 1 / 20	380,034	3444	25.20
	NC(12.6)/K_2SO_4/DPA/HMX			
	98 / 1 / 1 / 0	346,383	3146	25.26
	93 / 1 / 1 / 5	352,123	3193	25.22
	88 / 1 / 1 / 10	357,839	3239	25.17
	83 / 1 / 1 / 15	360,781	3259	25.12
	78 / 1 / 1 / 20	369,196	3329	25.08
	NC(12.6)/HMX			
	100 / 0	346,903	3088	24.76
	80 / 20	371,939	3307	24.73
	60 / 40	395,758	3514	24.69
	40 / 60	417,915	3702	24.64
	20 / 80	438,137	3870	24.56

(1) Solid carbon in combustion products

TABLE 3 CONTINUED

Ingredient	Formulation	Impetus, Ft-lbs/lb	T_{cv}, °K	Mean Molecular Weight
C. TAMED[1]				
	NC(12.6)/TAMED/HMX			
	25 / 75 / 0	213,763	1546	20.11[3]
	25 / 55 / 20	258,496	1753	18.86
	25 / 35 / 40	295,776	1974	18.56
	25 / 15 / 60	395,698	2961	20.81
D. TMAN[2]				
	NC(12.6)/TMAN/HMX			
	25 / 75 / 0	231,377	1596	19.18[3]
	25 / 55 / 20	281,809	1843	18.18[3]
	25 / 35 / 40	327,518	2185	18.55
	25 / 15 / 60	405,323	3132	21.49
E. BETN[4]				
	NC(12.6)/BETN/HMX			
	25 / 75 / 0	200,821	1545	21.39
	25 / 55 / 20	246,325	1778	20.07
	25 / 35 / 40	321,231	2331	20.18
	25 / 15 / 60	397,908	3222	22.52
F. EDNA-EDH[5]				
	NC(12.6)/EDNA-EDH/HMX			
	20 / 60 / 20	360,519	2336	18.02
	20 / 50 / 30	382,667	2585	18.78
	20 / 30 / 50	417,004	3119	20.80

(1) TAMED - bis-Tetramethyl ammonium ethylene dinitramine
(2) TMAN - Tetramethyl ammonium nitrate
(3) Solid carbon in combustion products
(4) BETN - Betain nitrate
(5) EDNA-EDH - Ethylene dinitramine ethylene dihydrazine

TABLE 3. CONTINUED

Ingredient	Formulation	Impetus, Ft-lbs/lb	T_{cv}, °K	Mean Molecular Weight
	Continued			
	30 / 60 / 10	344,859	2245	18.10
	30 / 50 / 20	368,720	2505	18.89
	30 / 30 / 40	404,053	3031	20.86
	NC(12.6)/EDNA-EDH/RDX			
	20 / 50 / 30	383,653	2597	18.82
	20 / 40 / 40	402,165	2852	19.72
	20 / 20 / 60	430,616	3403	21.98
G. DHED (1)	BUTAREZ/DHED/HMX			
	14 / 0 / 86	384,802	2641	19.10
	14 / 5 / 81	374,208	2531	18.81
	14 / 10 / 76	365,381	2442	18.59
	14 / 15 / 71	355,570	2352	18.41
	NC(12.6)/DHED/HMX			
	25 / 75 / 0	353,889	2296	18.04
	25 / 65 / 10	370,552	2489	18.68
	25 / 55 / 20	385,707	2690	19.94
	25 / 45 / 30	399,684	2901	20.18
	EC/DHED/HMX			
	25 / 75 / 0	247,677	1635	18.36 (2)
	25 / 45 / 30	272,236	1799	18.38 (2)
	25 / 35 / 40	281,877	1865	18.40 (2)
	25 / 25 / 50	293,756	1951	18.48 (2)

(1) DHED - Dihdrazine ethylene dinitramine
(2) Solid carbon in combustion products

TABLE 3. CONTINUED

Ingredient	Formulation	Impetus Ft-lbs/lb	T_{cv}, °K	Mean Molecular Weight
H. DMED[1]	NC(12.6)/DMED/HMX			
	20 80 0	297,173	1984	18.57[3]
	20 70 10	318,811	2131	18.58[3]
	20 60 20	344,296	2342	18.91
	25 75 0	299,465	2011	18.67[3]
	25 65 10	321,561	2169	18.76
	25 55 20	349,408	2420	19.26
	30 70 0	302,323	2044	18.80[3]
	30 60 10	326,592	2231	19.00
	30 50 20	353,393	2495	19.64
I. ISO-DMED[2]	NC(12.6)/ETC/DMED/ISO-DMED/HMX			
	19 1 64 0 16	330,616	2212	18.61
	19 1 48 16 16	343,156	2285	18.52
	49 1 50 0 0	326,312	2286	19.48
	49 1 0 50 0	363,718	2536	19.39
	50 0 0 50 0	357,197	2520	19.62
	50 0 0 40 10	371,657	2732	20.44
	50 0 0 30 20	384,101	2951	21.36

(1) DMED - Dimethyl ethylene dinitramine
(2) ISO-DMED - Isomer of DMED
(3) Solid carbon in combustion products

TABLE 3. CONTINUED

Ingredient	Formulation	Impetus Ft-lbs/lb	T_{cv}, °K	Mean Molecular Weight
	NC(12.6)/ISO DMED/TAGN			
	30 / 70 / 0	355,016	2333	18.28
	50 / 50 / 0	357,197	2520	19.62
	70 / 30 / 0	355,491	2731	21.38
	40 / 40 / 20	363,885	2539	19.4
	30 / 30 / 40	370,416	2556	19.2
	20 / 20 / 60	376,804	2572	19.0
	15 / 15 / 70	379,948	2579	18.9
	10 / 10 / 80	383,061	2587	18.8
J. TAGED(1)				
	BUTAREZ/TAGED/HMX			
	14 / 0 / 86	384,802	2641	19.10
	14 / 5 / 81	372,279	2519	18.81
	14 / 10 / 76	361,864	2428	18.86(2)
	14 / 15 / 71	351,526	2349	18.59(2)
	NC(12.6)/TAGED/HMX			
	25 / 45 / 30	392,804	2765	19.57
	25 / 55 / 20	374,173	2520	18.73
	25 / 65 / 10	352,077	2286	18.05
	25 / 75 / 0	328,912	2094	17.70

(1) TAGED - Triamino guanidine ethylene dinitramine
(2) Solid carbon in combustion products

TABLE 3. CONTINUED

Ingredient	Formulation	Impetus Ft-lbs/lb	T_{cv}, °K	Mean Molecular Weight
	NC(12.6)/IDP/TAGED/HMX			
	20 / 5 / 25 / 50	386,405	2712	19.52
	20 / 5 / 35 / 40	366,966	2468	18.70
	20 / 5 / 55 / 20	328,084	2100	17.80
	20 / 5 / 65 / 10	310,633	1979	17.71
	25/5 / 40 / 30	353,771	2336	18.36
	25 / 5 / 50 / 20	330,873	2138	17.97
	25 / 5 / 60 / 10	312,937	2008	17.84
K. TAGN (1)				
	BUTAREZ/TAGN/HMX			
	12 / 10 / 78	391,013	2691	19.14
	12 / 20 / 68	376,990	2535	18.70
	14 / 0 / 86	384,802	2641	19.10
	14 / 5 / 81	377,109	2561	18.89
	14 / 10 / 76	371,284	2501	18.73
	14 / 15 / 71	364,035	2432	18.58
	R-45M/TAGN/HMX			
	14 / 10 / 76	373,685	2530	18.83
	14 / 13 / 73	369,945	2493	18.74
	14 / 15 / 71	367,441	2469	18.69
	15 / 10 / 75	362,700	2443	18.73
	15 / 13 / 72	359,118	2410	18.66
	15 / 15 / 70	355,589	2378	18.60 (2)

(1) TAGN - Triamino guanidine nitrate
(2) Solid carbon in combustion products

TABLE 3 CONTINUED

Ingredient	Formulation	Impetus Ft-lbs/lb	T_{cv}, °K	Mean Molecular Weight
	NC(12.6)/TAGN			
	100 / 0	346,903	3088	24.76
	80 / 20	355,880	2971	23.21
	60 / 40	364,532	2864	21.85
	40 / 60	372,950	2768	20.64
	20 / 80	381,167	2681	19.56
	NC(12.6)/IDP/TAGN/HMX			
	15 / 5 / 80 / 0	348,138	2245	17.93
	15 / 5 / 70 / 10	360,720	2375	18.31
	15 / 5 / 60 / 20	373,390	2519	18.76
	15 / 5 / 50 / 30	384,456	2656	19.22
	20 / 5 / 75 / 0	348,069	2270	18.14
	20 / 5 / 65 / 10	360,600	2404	18.54
	20 / 5 / 55 / 20	373,184	2551	19.01
	20 / 5 / 45 / 30	384,254	2692	19.49
	25 / 5 / 70 / 0	349,703	2315	18.41
	25 / 5 / 60 / 10	361,899	2415	18.84
	25 / 5 / 50 / 20	374,170	2601	19.33
	25 / 5 / 40 / 30	385,041	2745	19.82

TABLE 3. CONTINUED

Ingredient	Formulation	Impetus Ft-lbs/lb	T_{cv}, °K	Mean Molecular Weight
L. Celcon	Celcon[1] /HMX			
	100 / 0	329,591	2011	16.97[3]
	80 / 20	356,492	2184	17.04
	60 / 40	399,151	2565	17.87
	40 / 60	433,526	3060	19.63
	20 / 80	455,508	3576	21.83
	Celcon[2] /HMX			
	80 / 20	214,011	1599	20.78[3]
	60 / 40	259,432	1822	19.53[3]
	40 / 60	340,711	2410	19.68
	30 / 70	381,393	2838	20.69
	20 / 80	416,117	3270	21.86
M. PA/MVT[4]	PA/MVT //HMX			
	100 // 0	257,273	1930	20.87[3]
	80 // 20	295,732	2134	20.07[3]
	60 // 40	354,458	2592	20.34
	40 // 60	403,507	3130	21.57
	20 // 80	439,727	3633	22.98

(1) Calculations made with ΔH_f = -42.4 kcal/100 gm
(2) Calculations made with ΔH_f = -133.3 kcal/100 gm
(3) Solid carbon in combustion products
(4) PA/MVT - Petrin acrylate/2-methyl 5-vinyl tetrazule copolymer

TABLE 3. CONTINUED

Ingredient	Formulation	Impetus, Ft-lbs/lb	T_{cv}, °K	Mean Molecular Weight
	PA/MVT // NC(12.6)			
	80 // 20	262,350	1947	20.64 (1)
	60 // 40	286,740	2134	20.70 (1)
	40 // 60	313,219	2437	21.64
	20 // 80	332,576	2760	23.08
N. NQ (2)				
	NC(12.6)/NQ /HMX			
	100 / 0 / 0	346,903	3088	24.76
	30 / 70 / 0	347,150	2730	21.87
	25 / 75 / 0	346,975	2706	21.69
	20 / 80 / 0	346,779	2682	21.51
	20 / 70 / 10	360,898	2835	21.84
	20 / 60 / 20	375,503	3000	22.22
	20 / 40 / 40	401,171	3314	22.98
	NC(12.6)/IDP/TAGN/HMX/NQ			
	18 / 5 / 59 / 18 / 0	371,053	2521	18.89
	18 / 5 / 54 / 18 / 5	372,376	2537	18.95
	18 / 5 / 49 / 18 /10	366,684	2519	19.10
	18 / 5 / 39 / 18/20	362,275	2516	19.32

(1) Solid Carbon in combustion products.
(2) NQ - Nitroguanidine

TABLE 3. CONTINUED

Ingredient	Formulation	Impetus Ft-lbs/lb	T_{cv}, °K	Mean Molecular Weight
O. PE [1]				
	NC(12.6)/HMX / PE			
	100 / 0 / 0	346,903	3088	24.76
	90 / 0 / 10	260,194	1935	20.68 [2]
	80 / 0 / 20	217,178	1680	21.51 [2]
	25 / 70 / 5	410,364	3229	21.88
	25 / 65 / 10	363,416	2576	19.71
	25 / 55 / 20	272,215	1906	19.47 [2]
	R-45M/ TAGN / HMX / PE			
	13 / 13 / 74 / 0	380,586	2590	18.92
	13 / 13 / 72 / 2	357,622	2392	18.60
	13 / 13 / 69 / 5	324,478	2183	18.71 [2]
	13 / 13 / 64 / 10	298,071	2034	18.97 [2]
P. R-Salt [3]				
	NC(12.6) / IDP / R-Salt			
	15 / 5 / 80	383,377	2613	18.96 [2]
	20 / 5 / 75	383,572	2611	18.93 [2]
	25 / 5 / 70	381,222	2602	18.98
	30 / 5 / 65	381,134	2626	19.16

(1) PE - Polyethylene
(2) Solid carbon in combustion products
(3) R-Salt - sym-Cyclotrimethylene trinitrosamine

TABLE 3. CONCLUDED

Ingredient	Formulation	Impetus Ft-lbs/lb	T_{cv}, °k	Mean Molecular Weight
	CARBOWAX BINDER / R-Salt			
	24 / 76	298,354 (1)	2156	20.10 (2)
	22 / 78	307,982	2212	19.98 (2)
	20 / 80	317,748	2270	19.87 (2)
	18 / 82	327,576	2330	19.78 (2)
	16 / 84	337,392	2391	19.71 (2)

(1) Carbowax Binder - Polyethylene oxide/Trimethylcol propane/Isonate 136T
(2) Solid carbon in combustion products

INITIAL DISTRIBUTION

USAF (SAMID)	1
AFSC (DLTW)	1
AFSC (SDWM)	1
ASD (ENYS)	1
FTD (PDXA)	1
AFML (LNP)	1
TAC (DRFM)	1
TAC (DMAM)	1
WRAMA (MME8L)	1
AEDC/ARO, Inc. (Lib/Docs)	1
AUL (AUL-LSE-70-239)	1
Chief of R&D (CRDAM)	1
Redstone Sci Info Ctr (Doc Sec)	1
USAWC (AMSWEREW)	1
USAMSAA (AMXRQ-AA)	1
USAR&D Ctr (AMXRD-BTL)	1
Frankford Arsnl (Lib, H1300, 81-51-2)	1
Picatinny Arsnl (SMUPA-RT-S)	1
NASC (AIR 350B)	1
USNWL (Code TR)	1
USNOL (Code 730)	1
NOS (Tech Lib)	1
NSC Tech Lib, T13	1
USNWC (Code 753/Tech Lib)	1
USNWC (Code 4585)	1
USNWEF (Code WE)	1
57 Ftr Spn Wg (FWOA)	1
CNO (OP-722)	1
USNRL (Code 2027)	1
LASL (Report Lib)	1
Battelle Memorial Inst Rpts Lib	1
IDA (Class. Lib)	1
Sandia Corp (Tech Lib ORG 3421)	2
The RAND Corp (LIB-D)	1
USAF TAC FWC (CRCD)	1
Harry Diamond Labs (AMXDO-TC)	1
DDC	2
TAWC (AY)	1
NOS (T-S73C4)	2
ASD (Tech Lib)	1
AFATL (DL)	1
AFATL (DLB)	1
AFATL (DLG)	1
AFATL (DLY)	1
AFATL (DLR)	1
AFATL (DLOSL)	2
AFATL (DLDL)	20
AFATL (DLDG)	1
ADTC (WE)	1

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