MERITS OF RDX

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ABSTRACT

The explosive properties of RDX have been compared in details with those of other high explosives, such as, picric acid, TNT, CE and PETN, in respect of (*i*) Rate of detonation, (*ii*) Brisance, (*iii*) Blasting power, (*iv*) Sensitivity, (*v*) Stability and (*vi*) Fragmentation. It has been pointed out that RDX is superior to all other modern high explosives hitherto used for blasting, shattering and fragmentation purposes.

Introduction

RDX is an important high explosive, developed and used, in large scale, during the World War II. Its high shattering and blasting powers proved it more useful than other explosives, available on production basis. Its high fragmentation effect against personnel and materials, together with its brisance and blasting properties, has proved it to be an unique high explosive during the World War II. It is, therefore, worthwhile to compare the explosive properties of RDX with those of the other modern high explosives.

The term RDX (Research Department Explosive) is applied to the substance *cyclotrimethylenetrinitramine*. RDX is also known as Cyclonite, Hexogen, T_4 etc. The substance was discovered as early as in 1899, but was not used as military explosive because of its high cost of production and comparatively high sensitivity. However, the potentiality of RDX as a high explosive was recognised after the World War I, and methods were developed to overcome these inherent difficulties. During the World War II, U.K., U.S.A., Canada, Russia, Italy, Germany, Japan all used this explosive.

RDX is superior to all other modern high explosives, such as TNT, CE, PETN etc. in many respects. The properties of an high explosive which make it particularly useful for military purposes are :—

(*i*) Rate of detonation, (*ii*) Brisance, (*iii*) Blasting Power, (*iv*) Sensitivity, (*v*) Stability, (*vi*) Fragmentation, etc.

Various explosives differ widely in the above properties. For each military use there are certain well defined properties which an explosive must possess and for each of such specific use, the particular explosive is selected, which best meets the rigid requirements.

The properties of RDX as military explosive have been considered and an attempt has been made, in this paper, to assess the importance of RDX in relation to the other high explosives used in the modern warfare.

So far the following substances have been used as military high explosives.

(*i*) Picric acid (Brit.-Lydite; Fren. Manilite).
(*ii*) TNT (Trinitrotoluene).
(*iii*) CE (Composition exploding; or tetryl).
(*iv*) PETN (Pentaerthythritoltetranitrate).
(*v*) RDX (Cyclo-trimethylenetrinitramine).

Rate of Detonation

The high explosives are substances which can be detonated and are used to give detonation. Detonation may be considered as a higher rate of explosion, which occurs in the absence of atmospheric oxygen and is characterised by the evolution of large quantities of heat and by the formation of large volume of gases. Detonation propagates through the explosive medium in the form of a mechanical or shock wave known as the detonation wave. The wave travels with velocities ranging between 2,000 to 9,000 meters per second according to the nature of the explosive. During the passage of the wave the molecules of the explosive are completely disrupted into their constituents. These constituents then recombine to form more stable molecules such as CO, CO_2, H_2, HO and N_2. The disruption of the molecules and recombination of the constituents liberate large amounts of energy, which is responsible for the further propagation of the wave. The sudden release of this energy, which generates very high pressures of the order of 300 tons per square inch, results in the detonation having intense shattering action.

The rate of detonation varies considerably in the different high explosives and may vary in a given explosive under different conditions. Under a given set of conditions the rate of detonation is constant; but increases with the apparent or loading density of the explosives.

The rates of detonation of modern high expl sives have been given in Table I at various loading densities.

TABLE I

Detonation Rate

Explosives	Detonation rate—meters/sec						
	Loading (pressed) density — gm/cc						Cost
	0·80	1·20	1·3	1·50	1·60[1]	1·70[2]	
Picric acid	..	5840	5980	6800	7100	7350	7350
TNT	4170	5560		6620	6900	..	6790
CE	4730	6110		7160	7500	7850	..
PETN	4760	6340		7520	7900	8300	..
RDX	5110	6550		7650	8250	8350	..

Table I shows that the rates of detonation, in cases of all the explosives, under study, increase with increase in loading densities. It is particularly of interest to point out that the rate of detonation of RDX is much higher than that of TNT, which is the normal explosive, filling. The rates of detonation of PETN at lower loading densitites are, however, comparable to those of RDX; but at densities above 1·5, RDX has a higher rate of detonation than PETN. RDX thus, shows a greater advantage over all other explosives in this respect.

Brisance

The Important Property which every high explosive must possess, is its capacity to shatter or disrupt the surrounding medium and is known as brisance. This property is different from that of the power or strength of a high explosive; brisance is dependent upon the rapidity of the reaction or detonation whereas explosive strength depends upon the quantity of gas evolved and the amount of heat given off. Brisance is sometimes compared to the effect of a blow as opposed to a push.

The brisance of a high explosive is indicated accurately by the determination of its rate of detonation. During the detonation of a high explosive, the material is consumed by the rapid physicochemical transformation as the detonating wave travels away from the point of initiation. The products of the detonation (usually gases) also travel in the same direction, so that there is a tendency to create a low-pressure area behind the wave, as well as the high pressure established by the wave itself. This accounts for the fact that when large quantities of high explosives are detonated, the low pressure created, may cause as much damage as the direct blast.

The brisance is usually measured by the sand test values—an early method which has lost some favour in the recent years. In this procedure, a fixed weight of standard sand, of known mesh size is enclosed in a bomb and is subjected to the shattering action of a standard charge of the explosive. The quantity of sand crushed is measured after re-sieving. The net weight of the sand crushed is called the sand test value, which is an index of brisance. The greater the sand test value, the higher is the brisance of the explosive. The explosives in use to day crush between 18 to 62 grams of sand by this test.

Another method, known as "plate—denting" test for measurement of brisance, is receiving more attention in recent years. A small bare charge is detonated, while resting on a steel plate of proper thickness. The depth of the dent in the plate measures the brisance. Many explosives have been subjected to these tests and certain useful conclusions have been reached.

The comparative brisances of the various explosives under investigation are given in Table II.

TABLE II

Comparative Brisances

Explosives	Rate of[1] detonation at loading density 1·6	Brisance[3] gm. sand*	Relative brisance
Picric acid	7100	47	1·00
TNT	6900	43	0·81
CE	7500	53	1·20
PETN	7900	62	..
RDX	8250	59	..

* Loaded under constant Pressure.

It is evident from table II that the brisance of the explosives under study increases with the increase in the rates of detonations. Tetryl is more brisant than TNT, the normal explosives filling. In this respect RDX is superior to TNT and Tetryl and is comparable to PETN.

The Blasting Power

The most important property of high explosives is its capacity to cause damage by blast in the vicinity of the point of explosion. The power or strength of explosion is considered to define the performance of an explosive at a distance or under the condition of confinement.

The power of an explosive depends on the quantity of gas evolved and the heat given off on explosion. Since the velocity of the explosion products depends upon the energy available to the system, it may be assumed that the blasting power is a function of the energy associated with the explosive.

The strength of an explosive is measured by the Ballistic mortar test, in which the amount of the explosive under test, that will raise a heavy ballistic pendulum to the same height as is raised by 10 gms of TNT is determined. These results show a fair agreement with the volume of the gaseous explosion products of various explosives.

The damage caused by an explosive may be localised or widespread. Hollow charge and squash head will cause a damage of the former type while that caused by high explosives is of the latter type. The widespread damage is mainly due to two causes viz, the fragmentation of the shell case and the damage caused by the blast after the explosion. The blast effect results from the sudden expansion of the gaseous products of explosion, formed at a very high temperature and pressure. Immediately after their formation the products start expanding in order to attain equilibrium with the surroundings. In doing so they give rise to a succession of waves of compression and rare factions of finite amplitude in the medium. This again confirms the view that the blasting power is proportional to the energy associated with the explosive.

The power of a high explosive is calculated by multiplying the heat developed in calories by the volume of gas evolved in c.c. per gram of the explosive, and reducing this to give a comparison with picric acid, as standard, to which a power of 100 is arbitrarily assigned. Hence the power of an explosive P is given by the formula :

$$P = \frac{Hx \times Vx \times 100}{H_1 \ V_1}$$

Where Hx and H_1 are the heat evolved per gram for the explosive and picric acid respectively and Vx, V_1, are the corresponding gas volumes.

TABLE III

Comparative Powers of Explosives

Explosive	Heat evolved[2] Cal/gm. H	Gases evolved [2] c.c./gm V	Explosive Power (Calculated) P	Relative blastic Power[4]
Picric Acid	1000	675	100	1·06
TNT	925	730	100	1·00
CE	1120	760	126	1·26
PETN	1385	790	162	..
RDX	1300	908	175	..

* In under water explosions the factor of superiority is still greater. 1 lb. of RDX mixture, as in torpex, is equal to more than 1·5 lbs. of TNT. As torpex is denser of the two, when considered on volume basis the factor of superiority approaches two.

It is evident from Table III that RDX is superior to TNT, CE and Picric acid in its explosive power*, but is equal to or only slightly superior to PETN in this respect. The heat of explosion and the gas volume values for these explosives also substantiate this comparison.

Sensitivity

Sensitivity is one of the most important properties of explosives. High sensitivity is an essential property of and low sensitivity is a requirement of a high explosive. Obviously, an explosive manufactured, loaded and generally handled in large quantities, must comparatively be insensitive for safety reasons. The initiators and boosters, which require high sensitivity to function properly are normally handled in smaller quantities.

The following three methods are used for measuring the sensitiveness of an explosive—

(*i*) *Impact sensitivity* is measured by a suitable drop test in which a 2-kg ball falls from different heights on a given sample of the explosive. In the Bureau of Mines type of machine, the unit of height is centimeter, whereas in the Picatinny Arsenal type, the unit is inch and there are other differences, such as the degree of confinement which renders the results on these two machines not directly comparable. The least height at which, one of ten trials, results in detonation is called the sensitivity value, and these values vary from 2 to 20 in. in the Picatinny Arsenal machine and from 5 to over 100 cms. in the Bureau of Mines machine. The larger this value, the lower is the actual sensitivity, because a higher height of drop is required to cause detonation or explosion of the sample.

(*ii*) *Friction sensitivity* is determined by a friction pendulum test in which a 7-gm sample of the explosive is exposed to the swinging action of a fibre or steel shoe. This test determines the qualitative behaviour of the explosive since sensitivity so measured is related to this particular type of action and the test merely determines whether the particular explosive is ignited, decomposed or detonated by the swinging action of the pendulum.

(*iii*) *Rifle bullet Impact sensitivity* is measured by penetration of a calibre 0·30 rifle bullet fired through a 1/2 lb sample of the explosive contained in a specified chamber. Because, it is desirable that loaded components, particularly bombs (which have thin cases, compared to artillery projectiles) should be safe against functioning by penetration of a rifle bullet. This test has long served as a measure of this kind of sensitivity.

Too much sensitive explosives are, no doubt, very useful in fuzes and are satisfactory for detonation purposes; but it will be extremely hazardous if these explosives are used to fill up bombs and shells. Hence the high explosives, unless distinctly insensitive, should not be used as a bomb or shell filler. The figure of sensitiveness in the case of high explosives under discussion are summarized in Table IV.

TABLE IV

Sensitiveness of Explosives[2]

Explosive	Impact test*		Friction Pendulum test†	Rifle Bullet test‡
	Picatinny in. machine	Bureau of mines machine cm		
Picric acid*	13	82	..	5
TNT	14	100	0	0·5
CE	8	26	0	7
PETN	6	17	5	10
RDX	8	18	2	10

* Minimum fall of 2 kg-wt to cause at least 1 explosion in 10 trials.

† Steel Shoe—number of explosions in 10 trials.

‡ Number of explosions in 10 trials.

It will be evident from the Table IV that RDX is more sensitive as compared to TNT and seems in this respect to be between CE and PETN. As such RDX is too sensitive for direct use as a burster and has to be used in conjunction with either wax or another nitro-body to overcome this difficulty.

Stability

An explosive is not acceptable for use in ammunition, if it does not possess a reasonable degree of stability. It is never known how much time will elapse between the actual loading of a component and its subsequent use. The storage period may be days or it may be years. Therefore, explosives are put in surveillance and are tested at certain intervals. In order to obtain advance surveillance data, accelerated tests at elevated temperatures are carried out by measuring loss in weight, quantity of gas evolved in vacuum, time of appearance of first traces of oxides of nitrogen, and the temperature at which a small sample will ingite, explode or decompose within a small interval of time.

Many explosives otherwise attractive have never found wide usage because of instability, and it is this factor more than any thing else, which resulted in the replacing of murcury fulminate by lead azide as the standard initiator.

The stability of the explosives under study are given in Table V.

TABLE V

Stability

Explosive	90 of gas evolved in 40 hrs in vacuum at 120°C
Picric acid	0·50
TNT	0·40
CE	1·00
PETN	11
RDX	0·9

It will be noticed that TNT is more than twice as stable as tetryl as judged by the above standard. Though in the same standard, the stability of RDX is lower than that of TNT, it is more stable than Tetryl and largely supersedes PETN in this respect.

Fragmentation

High explosive shells are employed to obtain demolition effect against material or fragmentation effect against personnel. For anti-personnel purposes, it is desirable to control the size of the fragments within certain limits, as the fragments, that are too small, are ineffective and the fragments that are too large, have low velocities and do not carry very far. In fragmentation the pertinent factors to be considered are the size, shape, weight, velocity and direction of the fragments, penetration of obstacles by them and their retardation in air etc. In order to obtain the desired fragmentation, the performance of various explosives and the wall thickness of the shell casing should be considered.

The fragmentation tests are carried out, to determine the effectiveness with which a high explosive filler will fragment a standard shell. Taking TNT as standard, the velocities as well as the average size of fragments in the case of various explosives under discussion have been tabulated below.

TABLE VI

Results of Fragmentation Tests

Explosives	Relative fragment velocity (calculated)	Relative fragmentation size (calculated)*
TNT	1	1
CE	1·2	0·64
Amatol—		
80/20 } 60/40 }	0·87	1·37
50/50	..	1·19
RDX/TNT, 60/40	1·10	0·81

* Calculations are based on the Moff's formula for the mass distribution of fragments.

From the above table, it will be evident that the velocity of fragments will increase by about 10 per cent and on the other hand the mean weight of fragments will decrease by about 20 per cent in the case of RDX/TNT (60/40) as compared to TNT alone. It is expected that in the case of pure RDX the increase in velocity and the decrease in the fragmentation size will be still more predominant. Hence it is evident that RDX composition not only gives much faster fragments, but also finer break-up of the shell whereas TNT produces larger break up of the casing and by far the slow fragments.

Discussion

It will be observed from the tables I to VI that RDX is superior to modern high explosives like picric acid, CE, TNT and PETN in the following respects—

(*i*) high detonation velocity,
(*ii*) high brisance,
(*iii*) high blasting power,
(*iv*) high temperature of explosion,
(*v*) large gas volumes on explosion,
(*vi*) better stability than CE and PETN,
(*vii*) high material density.

RDX is of the same order of brisance as PETN, as indicated by sand test and rate of detonation values (Table II). PETN being highly sensitive, is used in primacord and cordtex for transmitting a detonation wave from one place to another without loss of time. On the other hand, when mixed with other high explosives, like TNT and RDX it serves as a filler for high explosive shells. The ballistic pendulum test (Table III) indicates that RDX is slightly superior to PETN in respect of explosive power and their heat of explosion and gas volumes substantiate this comparison. RDX may, therefore, be considered superior to any other solid bursting-charge explosive available on a production basis. The stability (Table V) and the high density* of the original material renders RDX superior to any other explosive, hitherto used for blasting purposes. Its impact sensitivity is nearly equal to that of CE, but it is somewhat more sensitive to friction and rifle bullet impact. RDX is, therefore, appreciably sensitive to impact as well as to friction making it inferior to TNT in this respect. This difficulty is overcome by using it in mixtures with inerts and other high explosives. Further RDX has a high melting point (204°C). This property of RDX does not allow it to be filled in bombs and shells by pouring in as melt. It is therefore mixed with TNT and is poured in as slurry which on cooling forms a rigid mass in the container.

In order to make it less sensitive RDX is generally mixed with small quantity of wax and is known as RDX composition A. Mixture of RDX with 7-9 per cent of wax is sufficiently plastic at 100°C and can be pressed into the shells etc. A mixture of RDX with wax is sometimes used as an intermediary. This mixture is as insensitive as TNT, but more brisant than TNT alone. It is loaded into a shell which is required to stand shock before detonation.

A mixture of RDX/TNT and a small quantity of wax is known as RDX composition B (and B_2 if wax is omitted). It can be cast and as such it is an ideal explosive for bombs. This mixture is specially suitable for fragmentation bombs, where sensitivity must be combined with high blast effect. The sensitivity of RDX B is little more than that of TNT; whereas its brisance is intermediate between TNT and RDX alone. RDX B_2 (RDX/TNT 60/40) has been found essential for high calibre air-craft bombs, specially made of forged steel.

A plastic explosive, known as RDX 'C' is formed by mixing about 90 per cent RDX with about 10 per cent plasticizer. It is about as insensitive as, but more brisant than TNT. It is, therefore, used in the demolition work and has been found very useful upon concrete fortification where it is required to spread over an explosive area at impact. An 88-12 RDX lubricating oil mixture is an example of a simple plastic explosive; but it lacks in the cohesiveness and resistance to changes with temperature. 77-23 RDX is a more suitable mixture, containing a plastic binder composed of nitro aromatic compounds and a small percentage of nitrocellulose. This composition is more cohesive, but it is more toxic and may undergo some segregation of blinder during storage at high temperatures.

RDX has also been used in combination with TNT and aluminium powder. This mixture is known as Torpex filling and is used in depth bombs and torpedo warheads.

Another important mixture of RDX is known as amatex. This is formed by mixing RDX with TNT and ammonium nitrate.

Besides its use as a high explosive in bursting charges, crystalline RDX[5] in a finely divided form has been found to be an important ingredient in a variety of propellant and detonator compositions.

As RDX may be obtained from the raw materials like formaldehyde, ammonia, and nitric acid, it offers distinct advantages over explosives, dependent upon petrolium or coke by products as basic material. It can be produced if only coal, water, air and electrical energy are available as starting material.

Acknowledgement

The authors are grateful to Prof. D.S. Kothari, Scientific Adviser to the Defence Minister, for his keen interest during the preparation of this paper.

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