Def Sci J, Vol 37, No 1, January 1987, pp 51–57

Studies on Some Aspects of Propellants for Improving the Performance of Tank Guns

K.P. Rao, P.K. Umrani, R.G.K. Nair and K. Venkatesan
Explosives Research & Development Laboratory, Pune–411021

ABSTRACT

The main criterion, in the design of propellant charge for a tank gun, is to achieve the highest possible muzzle velocity for fin stabilized armour piercing discarding sabot (FSAPDS) projectiles. This ensures penetration through the toughest armour plates by the kinetic energy of the projectile. One of the solutions, is to increase the force constant of the propellant. Higher force constants from conventional double and triple base propellant compositions lead to prohibitive linear rates of burning coefficients. ERDL has developed a high energy propellant based on RDX, with very high force constant and low linear rate of burning coefficient. The objective of the present paper is to discuss various aspects of the interior ballistics of the three types of propellants in question in 105 mm tank gun with FSAPDS ammunition. The study shows that only the solution with RDX base propellant is feasible for an increase of three per cent in muzzle velocity.

Notations

C	charge mass (kg)
D	web size (cm)
E	efficiency of the gun (%)
F	force constant (J/g)
n	number of moles of product gases (g. mole/g)
P	pressure (MPa)
Pm	maximum pressure (MPa)
r	rate of burning of propellant (cm/s)
R	universal gas constant (J/mole/°K)

Received 25 August 1986

T isochoric flame temperature (°K)
muzzle velocity of the projectile (m/s)
W projectile mass (kg)
β linear rate of burning coefficient (cm/s/MPa)
ratio of specific heats of gases

INTRODUCTION

The requirement for the highest possible muzzle velocity for a tank gun, is to ensure enhanced penetration by kinetic energy or to get increased effective range. Guns under development stage and also existing ones need a careful consideration for improving their performances, for in case of existing guns, an increase of one per cent in muzzle velocity increases the effective range to the extent of 300 m. There are a number of aspects to be considered, having either direct or indirect impact on the gun and ammunition systems. The object of this paper, is to discuss various aspects of propelling charges for tank guns. Though the problem has been studied in the case of 105 mm tank gun, fin stabilized armour piercing discarding sabot (FSAPDS) ammunition, the results reported in this paper are fairly applicable to other such similar systems.

2. MUZZLE VELOCITY

The expression for the muzzle velocity v of a gun in its simplest form is given by

$$v^2 = \frac{20\,F\,C\,E}{(\gamma - 1)\,(W + C/3)}$$

In Eqn. (1), the function E, depends on shape of the propellant charge, maximum pressure of the gun Pm and expansion ratio of the gun. Having optimised the shape of the propellant charge, there is no scope left for improving this function in the case of an existing gun.

Having reached the maximum practicable loading density, further increase of charge mass is not possible, with the known propellants without increasing the chamber capacity of the gun. The only considerations left are the force constant F of the propellant and ratio of specific heats of propellant gases γ. From Eqn. (1), it is desirable to have very high values of F and low values of γ to achieve the highest possible muzzle velocity.

3. FORCE CONSTANT OF PROPELLANTS

The expression for the force constant, F, of a propellant is given by

$$F = n\,R\,T_0 \qquad (2)$$

From the Eqn. (2), an increase of F implies either an increase of n, the number of moles of product gases or an increase in isochoric flame temperature T_0 or an increase in both. An increase of F by an increase in T_0 is not desirable for two reasons. Firstly, higher isochoric flame temperature produces excessive barrel erosion and results in poor gun life. Secondly, propellants of the same type, will have higher rates of burning coefficients, with higher isochoric flame temperature and to overcome this the web size of the grain will have to be increased. This results in poor loadability, manufacturing problems and brittle-fracture of the grain especially at cold temperatures.

4. CONVENTIONAL PROPELLANTS

Hitherto, the propellants used in the guns are of three types, viz. (i) single base propellants containing NC, (ii) double base propellants containing NC, and NG, (iii) triple base propellants containing NC, NG and picrite, along with some additives like diphenylamine, centralite etc. in the matrix.

The relevant features of these are given below :–

(i) Single base propellants — The scope of improving the force constant of these propellants is limited due to acute oxygen deficiency in NC. Force constants beyond 1050 J/g, are not possible and these propellants have no further scope for improvement.

(ii) *Double base propellants* — These are capable of giving high force constants. NG has an excess of oxygen, while NC is deficient in oxygen. The mixture ratio yielding the highest force constant is about stoichometric i.e. the mass ratio of NG to NC should be about 8.6. It is not possible to obtain a propellant gel with good mechanical properties beyond NG percentage exceeding fifty. These propellants give high force constants by virtue of high T_0 in spite of having low value of n. These have low values of γ. Force constants of the order of 1170 J/g can be obtained.

(iii) *Picrite propellants* — These are being extensively used in tank guns. These have moderately higher force constants at relatively lower isochoric flame temperatures, larger number of moles of product gases and higher ratio of specific heats than double base propellants.

5. HIGH ENERGY PROPELLANTS

Extensive research has been carried out to improve upon the force constant by virtue of increased values of moles per gram of product gases rather than increasing isochoric flame temperature.[2] In order to get higher value of n the mean molecular mass of the product gases should be as low as possible. The main constituents of the product gases are CO_2, CO, H_2O, H_2 and N_2. The product gases should have very small proportion of CO_2 and very high proportion of H_2. In view of this, a number of oxidisers like TAGN, TAGP, NAG, RDX, HMX, etc., have been studied. Of these, propellants containing RDX, have been found to be very promising. These propellants have very high force constants at relatively low isochoric flame temperatures, large number of moles of product gases per gram of propellant and high ratio of specific heats.

6. RATE OF BURNING COEFFICIENTS OF PROPELLANTS

The rate of burning r is proportional to pressure P and is given by

$$r = \beta P \tag{3}$$

The linear rate of burning coefficient β in the solution of interior ballistics of guns is of great importance and it always occurs as β/D (termed as vivacity), D being the web size of the propellant. For a tank gun propellant the value of β should be as low as possible for otherwise to offset the higher values of β the web size has to be higher and this results in poor loadability and manufacturing problems.

7. RESULTS

The internal ballistics have been computed for a 105 mm tank gun, FSAPDS ammunition. The gun data have been given in Table[3] 1. Four types of propellants

Table 1. Gun and ballistic data.

Gun	105 mm tank gun
Ammunition	FSAPDS
Maximum pressure	415 MPa
Muzzle velocity	1500 m/s
Calibre	105 mm
Shot travel	475 cm
Chamber capacity	6554 cm^3
Projectile mass	5.8 kg

have been considered for studying the interior ballistics problem. The propellants have been designated as NQ, HNP, HSC and RDX. NQ and HNP are triple base propellants, HSC is a double base propellant and RDX is a composition containing NC, RDX and other additives. The products of explosion of these formulations have been computed[4] and given in Table 2.

All the relevant propellant data, required for computing the internal ballistics have been given in Table 3. The propellant data, of NQ and HSC have been directly

Table 2. Products of explosion.

Constituents	mole/g			
	NQ	HNP	HSC	RDX
$CO_2 \times 10^2$	0.2058	0.4061	0.6197	0.1871
$CO \times 10^1$	0.1269	0.1040	0.1337	0.1756
$H_2O \times 10^2$	0.9673	1.1730	1.0900	0.7337
$H_2 \times 10^2$	0.7252	0.3455	0.2704	0.7830
$N_2 \times 10^1$	0.1304	0.1113	0.0539	0.0992
$O_2 \times 10^7$	0.1065	106.00	864.50	2.3040
$O \times 10^7$	0.1970	78.390	541.60	6.1460
$OH \times 10^4$	0.1799	1.4230	0.2272	0.4199
$H \times 10^4$	0.4727	1.1330	1.4190	1.2940
$NO \times 10^6$	0.9889	73.400	202.50	8.0060
$N \times 10^6$	0.1962	7.0570	17.600	2.6760

taken from reference (5). The linear rates of burning coefficients of these have been evaluated by closed vessel experiments.

Solution with propellant NQ, has been taken as the reference case, which meets the requirement of existing ballistics viz., muzzle velocity of 1500 m/s and maximum pressure in the gun not greater than 415 MPa. In order to study the improvement in muzzle velocity, solutions with other types have been computed, keeping the charge mass same as that of NQ, and by varying, the web size of the propellant to realise a maximum pressure of 415 MPa, in the gun. The shape of the propellants have been

Table 3. Propellant data.

Parameter	NQ	HNP	HSC	RDX
Isochoric flame temperature (°K)	2850	3386	3600	3239
Force constant (J/g)	1060	1150	1168	1202
Co-volume (cm^3/g)	0.958	0.924	0.936	0.983
Ratio of specific heats	1.25	1.23	1.22	1.26
Mean molecular mass of product gases (g/mole)	22.4	24.4	25.6	22.4
Mole/g of product gases of the propellant	0.0446	0.0410	0.0391	0.0446
Density (g/cm^3)	1.67	1.58	1.61	1.65
Linear rate of burning coefficient (cm/s/MPa)	0.12	0.19	0.25	0.14

heptatubular grains having circular cross-section. The solutions of the interior ballistics of all the four propellants have been given in Table 4.

Table 4 Computed ballistics.

	NQ	HNP	HSC	RDX
Charge mass (kg)	5.57	5.57	5.57	5.57
Web size (cm)	0.108	0.179	0.233	0.136
P_{max} (MPa)	415	415	415	415
Muzzle velocity (m/s)	1500	1540	1550	1550

8. CONCLUSIONS

1. The results of Table 1 show that RDX propellant has got the lowest concentration of CO_2 and H_2O and highest concentration of CO and H_2 in the explosion products, thereby decreasing the mean molecular mass of the product gases than the other propellants. This is due to the absence of NG and the presence of high percentage of RDX in the RDX propellant.

2. The results of Table 3 show that RDX propellant has the lowest isochoric flame temperature of 3239°K for a force constant near about 1200 J/g. The use of this propellant in the gun, reduces the barrel erosion significantly..

3. Among all propellants with force constants near about 1200 J/g, RDX propellant has got the lowest linear rate of burning coefficient, in relation to its force constant to any other propellant. This is due to the combustion mechanism, involving the formation of a melt layer of RDX.[6] This brings down drastically the web size of the propellant needed (Table 4) and as a result, it is easier to extrude this propellant than the other propellants like HNP, HSC etc. and improves the loadability, leaving a scope for further increase in muzzle velocity.

4. RDX propellant has got the highest value of force constant among all the propellants and also the highest value of ratio of specific heats. Due to the latter, fullest advantage of the force constant cannot be utilised to improve the performance. Though HSC and HNP propellants have lower force constants than RDX due to their lower values of ratio of specific heats, the muzzle velocity realised, is on par with that of RDX propellant. The calculations show, scope of three per cent increase in muzzle velocity over the existing NQ propellant.

From the above, a careful consideration of the advantages and disadvantages of different propellants shows that RDX propellant is the best choice for improving the overall performance of the tank guns.

ACKNOWLEDGEMENTS

The authors express their sincere thanks to Dr. K.R.K. Rao, Director, ERDL, Pune for his encouragement and kind permission to carry out the present study.

REFERENCES

1. Herman, K. & Summerfield, M., Interior Ballistics of Guns (American Institute of Aeronautics and Astronautics), **66,** 1979, pp. 12–14.
2. Heiney, O.K., *National Defence,* September-October (1973),152–57.
3. Rocchio, J.J., Deas, R.W. & Frankle, J.M., High performance propelling charge designs for 105 mm, M-68 Tank Gun, Fourth International Symposium on Ballistics, California, October 1978.
4. Rao, K.P., *Def. Sci. J.,* **29,** (1979), 21–26.
5. Internal Ballistics, HMSO, 1951, pp 224–26.
6. Kumar, R.N. & Strand, L.D., Analytical investigation of the combustion process occuring in advanced nitramine based propellants, Technical Report AFATL-TR-74-155, Sept. 1974, pp. 6.