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Liquid Propellants for Advanced Gun Ammunitions

K.P. Rao, A.S. Bartakke and R.G.K. Nair
Explosives Research & Development Laboratory, Pune-411021

ABSTRACT

With constant improvements, the conventional solid propellants for guns have almost reached their limit in performance. Liquid gun propellants are promising new comers capable of surpassing these performance limits and have numerous advantages over solid propellants. A method has been worked out to predict the internal ballistics of a liquid propellant gun and illustrated in a typical application.

Notations

- A area of cross-section of the bore
- C charge mass of the propellant
- F specific energy of the propellant
- l initial length of the combustion chamber
- m mass of propellant consumed in the combustion chamber
- P pressure in the combustion chamber
- T explosion temperature
- t time
- v velocity of the shot
- W mass of the shot
- x shot travel
- γ ratio of specific heats

1. INTRODUCTION

Extensive research that has been carried out on solid propellants and their energy transfer techniques for improving the performance of guns, has resulted in arriving

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at a number of solutions. These include, the use of nitramines like RDX in the propellant matrix, base bleeding unit technique, rocket assisted projectiles, inhibited propellant grains, improved geometry of propellant grains etc. However, all these solutions have proved to give only marginal improvement in the performance of the guns. The studies show that the maximum specific energy limit of solid propellant has been almost reached with the known raw materials. In view of this, efforts are being made for alternate propelling charge systems, using liquid propellants for obtaining substantial increase in the performance of guns. Most of the liquid propellants for guns have higher specific energies than conventional solid propellants for nearly equal explosion temperatures.[1] By tailoring the plateau of the pressure-time curve using a regenerative injection system, it is possible to obtain very high muzzle velocities and by continuous variation of the propellant charge mass, different ranges for the projectile can be obtained without changing the elevation of the gun.[2] They also offer significant logistical advantages with regard to storage, transport, ammunitioning process and cost.[3] This has opened up new avenues in the field of gun propellants. In this paper, a method to evaluate the performance prediction of liquid propellant for guns is discussed.

2. INTERNAL BALLISTICS

The method of prediction consists of two parts (1) a method to calculate the chemical equilibrium composition and specific energy and (2) a method to predict the interior ballistics.

A set of equations have been worked out for chemical equilibrium composition using the fundamental approach[4] and these equations have been solved on a Hewlett-Packard 9825 computer. The results of the calculations are tabulated in Table 1. The results corroborate the reported values.[5] The calculations also reveal that the optimum specific energy is realised at an oxygen balance of –10 to –30 per cent for the bipropellants. It is also seen that the bipropellant combination hydrazine and nitrogen tetroxide gives the highest specific energy of 1606 J/g. This is about 40% higher than that of the solid propellant M8 (which has the highest specific energy amongst conventional solid propellants).

The main objective of computing internal ballistics of a regenerative feed system liquid propellant gun is to find the mass of the propellant required in the gun chamber for obtaining the desired pressure-time profile. Since the literature available on the subject is scanty, the basic assumptions and complete procedures have been discussed in the succeeding paragraphs.

2.1 Assumptions

(i) All the propellant that enters the combustion chamber of the gun is perfectly homogeneous and combustion takes place instantly.

(ii) The secondary energy losses due to heat transfer to the gun, friction, strain, etc., have been neglected and the same can be accounted in the efficiency factor.

(iii) No pressure gradient exists between the combustion chamber and base of the projectile.

(iv) The co-volume of the propellant gases is negligible.

2.2 Solution

The solution is found by solving the three simultaneous equations from Eqn. (1 to (3).

$$Fm = PA\ (x+l) + 0.5\,(\gamma-1)\,W\ v^2 \qquad (1)$$

$$dv/dt = AP/W \qquad (2)$$

$$dx/dt = v \qquad (3)$$

The solution from shot start to shot ejection is obtained by selecting a proper time interval.

The initial conditions are : when $t = 0, x = 0, v = 0$ and the mass of the propellant required to develop the initial pressure is given by

$$m = APl/F \qquad (4)$$

Let Δt, Δv and Δx be the increments of time, velocity and shot travel respectively. Suffixes 0, m, and 1 denote the start, mean and end values of a variable during an interval.

$$t_1 = t_0 + \Delta t \qquad (5)$$

$$\Delta v = (AP/W)\Delta t \qquad (6)$$

$$v_1 = v_0 + \Delta v \qquad (7)$$

$$v_m = 0.5(v_0 + v_1) \qquad (8)$$

$$\Delta x = v_m\ \Delta t \qquad (9)$$

$$x_1 = x_0 + \Delta x \qquad (10)$$

$$x_m = 0.5(x_0 + x_1) \qquad (11)$$

Using these mean values, the mass of propellant for pressure P, in the gun chamber is given by

$$m = [AP(x_m + l) + 0.5(\gamma-1)\ Wv^2_m\ ]/F \qquad (12)$$

Now, the values of t_1, x_1 and v_1 are taken as initial values for the next step and the equations from Eqn. (5) to (12) are recomputed. The procedure is continued till the muzzle end is reached.

The highest possible muzzle velocity is obtained when the working pressure in the bore of the gun is maintained constant from shot start to shot ejection.

The efficiency of a liquid propellant gun is not precisely known at the present stage, but expected to be of the order of 15 to 20 per cent. The charge masses required for various liquid propellants to realise a muzzle velocity of 2400 m/s in a hypothetical 105 mm gun have been computed and included in Table 1.

Table 1. Computed data on liquid propellants

Propellant system	T (K)	F (J/g)		C (kg)
Isopropylnitrate	1675	798	1.28	32
Nitromethane	3086	1263	1.24	20
Hydrazinenitrate	2884	1075	1.22	24
Hydrazine 42% + Nitrogentetroxide 58%	3342	1606	1.22	16
Hydrazine 30% + Hydrazinenitrate 70%	2732	1309	.25	19
Hydrazine 65% + Hydrazinenitrate 30% + Water 5%	1706	1081	1.32	24
Hydrazine 39% + Nitric acid 61%	3675	1447	1.21	18
Monomethylhydrazine 29% + Nitric acid 71%	3792	1383	.21	18
Triethylamine 20% + Nitric acid 80%	3757	1285	1.20	20
Furfurylalcohol 30% + Nitric acid 70%	3780	1148	1.20	22
Hydrazine 32% + Hydrogenperoxide 68%	3509	1492	1.20	17
Kerosene 25% + Nitric acid 75%	2984	1166	1.24	22

The pressure-time curve of a liquid propellant and that of a solid propellant M8, in a typical gun are shown in Fig. 1 It may be noted that muzzle velocity beyond 1500 m/s is not possible by any of the solid propellants for a proportionate gun.

The propellant mass consumption versus time has been worked out and shown in Fig.2, for all the liquid propellants discussed in Table 1, so as to obtain the pressure-time profile in Fig. 1.

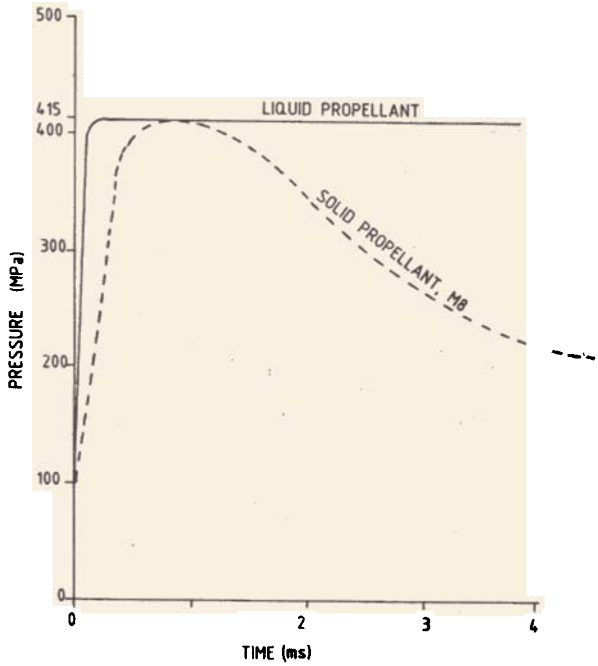

Figure 1. Pressure – time curves in a hypothetical 105 mm gun

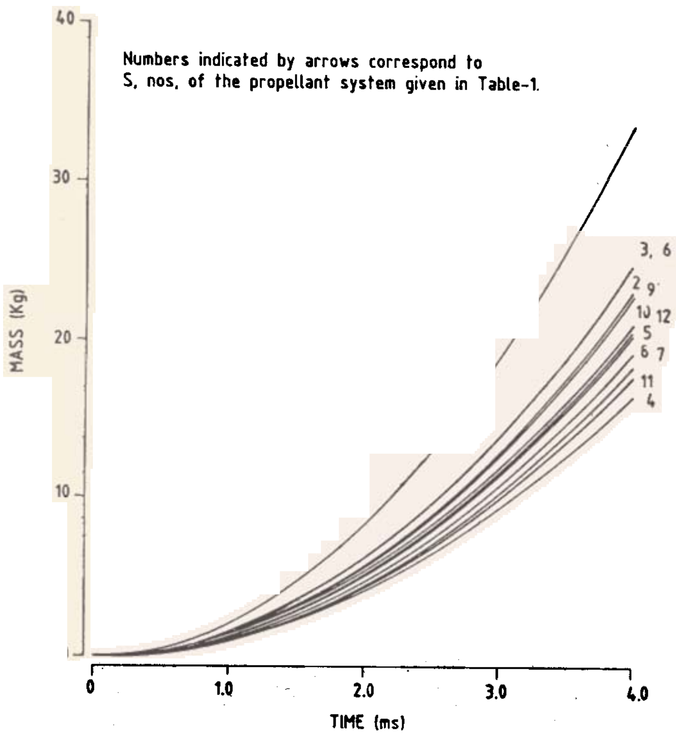

Figure 2. Propellant consumption time curves.

Although, considerable amount of work has been carried out on experimental liquid propellant guns of various calibres, a gun for operational use is yet to emerge.

3. CONCLUSION

It would be seen that liquid propellants possess considerable advantage over solid propellants. The method described can be utilized for performance evaluation of liquid propellants in guns. Based on actual experiments, the equations discussed in the paper may have to be modified for more realistic results.

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REFERENCES

1. Morrison, W.F., Knapton, J.D. & Klingenberg, G., Liquid propellants for gun applications, Proceedings of the Seventh International Symposium on Ballistics, The Hague,1983, pp. 63-77.

2. Morrison, W.F., Knapton, J.D. & Klingenberg, G., *J. of Ballistics* ,**8** (1985), 2026–2060.

3. Witt, W. & Reinelt, K., *IDR*, **14** (1981), 110–112.

4. Huff, V.N., Gordon, S. & Virginia, E.M., General method and thermodynamic tables for combustion of equilibrium composition and temperature of chemical reactions report 1037, NACA, 1951, pp. 2–8.

5. Volk, F., Hund, M. & Schmitt, D., Hypergolic liquid propellants for gun system Fifth International Symposium on Ballistics (France), 1980, pp. 62–69.