# APPLICATION OF CLOSED VESSEL TECHNIQUE FOR THE EVALUATION OF BURNING RATES OF PROPELLANTS AT LOW PRESSURES

D. VITTAL

Explosive Research & Development Laboratory, Pune

(*Received 5 May, 1976*)

Closed vessel technique has been well established for the evaluation of burning characteristics of gun, mortar and small arms propellants at high pressures of about 750 kg/cm$^2$—3000 kg/cm$^2$ (73·55 MPa—294·2 MPa). Strand burner technique is used for measuring the rate of burning of rocket propellants in the pressure range up to about 200 kg/cm$^2$ (19·6 MPa). One of the modern trends in armament technology is development of short range, high efficiency rockets and rocket assisted projectiles where the chamber pressures are in the range of 100 kg/cm$^2$—800 kg/cm$^2$ (9·8 MPa—78·5 MPa). An extension of the closed vessel technique is now presented for the measurement of rates of burning of propellants in this pressure range and a few experimental results on some conventional propellants are given.

## NOTATIONS

$A$ = Cooling rate constant representing losses due to radiation.

$C$ = Charge weight of the propellant in the closed vessel.

$(C)$ = Gram atoms of carbon per gram of the propellant.

$D$ = Effective web size of the propellant grains.

$F$ = Force constant of the propellant.

$K$ = Cooling rate coefficient representing losses other than those due to radiation.

$(O)$ = Gram atoms of oxygen per gram of the propellant.

$P$ = Pressure.

$P_m$ = Maximum pressure reached in the closed vessel.

$R$ = Gas constant.

$T_o$ = Adiabatic flame temperature of the propellant gases.

$V$ = Volume of the closed vessel.

$a$ = Muraour's zero rate of burning.

$b$ = Covolume correction factor.

$f$ = Fraction of the web size (D) burnt at any time during burning of the propellant.

$n$ = Number of gram moles of gas produced per gram of the propellant.

$r$ = Rate of recession of the burning propellant surface, popularly called the rate of burning.

$t$ = time.

$\alpha$ = Pressure index in Vielle's law.

$\beta$ = Rate of burning coefficient in Vielle's law.

$\beta_1$ = Rate of burning coefficient in Piobert's law.

$\beta_2$ = Rate of burning coefficient in Muraour's law.

$\triangle$ = Loading density of propellant in the closed vessel.

$\delta$ = Density of the solid propellant.

$\eta$ = Covolume of the propellant gases.

$\theta$ = Conventional form factor of the propellant grains.

$\phi$ = Fraction of charge weight ($C$) burnt at any time ($t$)

Strand burner techniques[1-3] are well established for measuring rates of burning at the very low pressure region up to about 200 kg/cm² (19·6 MPa). At high pressures, approximately from 750 kg/cm²—3000 kg/cm² (73·55 MPa—294·2 MPa) and above, in which region guns, howitzers, small arms and high efficiency mortars operate, the rates of burning are computed by the well established closed vessel technique[4-7]. The closed vessel technique has been adopted and extended at ERDL to measure the rates of burning in the pressure region of 100 kg/cm² — 800 kg/cm² (9·8 MPa — 78·5 MPa).

The modern trend in armament technology is for the introduction of short range, high efficiency rocket and rocket assisted projectiles for antitank, antipersonnel, demolition and similar purposes, and many of these weapons work at chamber pressures in the above range. So the discussed ERDL version of the closed vessel method is expected to be very useful in the design of such weapons.

The closed vessel technique consists in the burning of a known weight of propellant in a constant volume vessel whose volume is accurately measurable and recording its pressure-time relationship during burning.

## COMBUSTION AT CONSTANT VOLUME

When the propellant charge burns at constant volume in the closed vessel, the pressure steadily rises to a maximum value which corresponds in time to the condition when all the propellant is burnt and then starts falling and continues to fall due to loss of heat from the gases to the walls of the vessel. The burning is governed by any of the following rate of burning laws whichever is applicable to the propellant :—

Piobert's law[7-8]

$$r = D \frac{df}{dt} = \beta_1 P \tag{1}$$

Muraour's law[9]

$$r = D \frac{df}{dt} = a + \beta_2 P \tag{2}$$

Vielle's law[10]

$$r = D \frac{df}{dt} = \beta P^a \tag{3}$$

The gas evolution rate is also controlled by the surface-volume relationship of the burning propellant grain, which is called the form function, the conventional form of which is :—

$$\phi = f\,(1 + \theta - \theta f) \tag{4}$$

The gases obey the Noble and Abel's modification of Van der Waal's equation of state[7,11,12] :—

$$P \left[ V - \eta C + \left(\eta - \frac{1}{\delta}\right) C\,(1 - \phi) \right] = n\,RT_o\,C\,\phi = F\,C\,\phi \tag{5}$$

## EXPERIMENTAL PROCEDURE AND COMPUTATIONS

The propellant composition whose rates of burning are to be measured is extruded in sticks of cord form of circular cross section. The diameter is kept at about 2·5 mm to 3·5 mm, length at approx. 12·5 cm to 14 cm and the length/diameter ratio equal to or greater than 50.

The density of the solid propellant is measured by the Bofor's method[13]. The covolume of the propellant gases is calculated using Corner's formula[14] :—

$$\eta = 1 \cdot 18 + 6 \cdot 9 \ (C) - 11 \cdot 5 \ (O) \quad (6)$$

when $(C)$ and $(O)$ are in gram. atoms/g, $\eta$ is in $cm^3/g$.

The force constant $(F)$ is roughly calculated from the propellant composition using the short, approximate method of Hirschfelder[15].

If the length/diameter ratio of the propellant grains are equal to or greater than 50, then the form factor $\theta$ for them is assumed to be $1 \cdot 0$. The form function of the cord form under these conditions very closely follows the theoretical form function equation (4) and for this reason cord form is used for this work.

Closed vessel firings are carried out at a suitable loading density to give an approximately predetermined $P_m$ value. Approximate charge weight to give the required $P_m$ is computed from :—

$$C = \frac{P_m \ V}{F} \quad (7)$$

$1 \cdot 3$ grams of gunpowder G 12 is used as igniter for the propellant charge and one or two test firings are carried out to ensure that the ignition is correct. If necessary the weight of gunpowder is suitably increased or decreased. $P$—$t$ curves are recorded for each firing. 5 repeat firings are carried out at each loading density. Measurements of pressure and time are made up to and including $P_m$ at 20—25 points spread evenly along the record.

A few blank firings are carried out with only the gunpowder igniter charge to estimate the pressure produced by the gun powder. This pressure is subtracted from each $P$ value and also from the $Pm$. Time to reach the gunpowder pressure on each record is marked and is assumed as the zero time for the time measurements. $A$ typical $P$—$t$ record is given in Fig. 1.

At each measured $P$ point, slopes are calculated to give $\frac{dP}{dt}$. Every value of $P$ and $\frac{dP}{dt}$ and $P_m$ is corrected for cooling loss by the procedure described by Vittal[16], using the following equations and computing $K$ and $A$ from the $P$—$t$ records if not already available :—

$$\frac{dP}{dt} = \left( \frac{dP}{dt} \right)_r + KP_r + A \quad (8)$$

$$P = P_r + K \int_0^t P_r \, dt + At \quad (9)$$

The subscript $r$ denotes recorded values. $K$ and $A$.

Values for a few conventional propellants are given in Table 1.

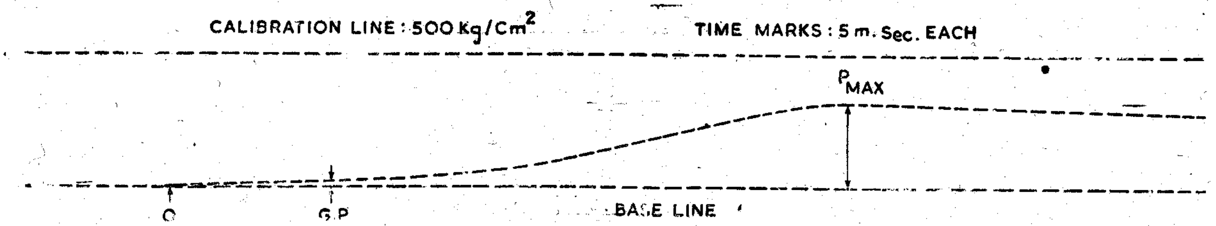


Fig. 1—Pressure-time record from closed vessel.

Table 1

Cooling rate correction factors for some conventional propellants

| Propellant | K (1/sec) | A (kg/cm². sec) |
|---|---|---|
| AN 150 | 1·14 | 24·0 |
| WM 150 | 1·11 | 42·1 |
| Ballistite cord 150 | 0·835 | 62·7 |
| N 050 | 0·846 | 19·4 |
| T—28 cord 150 | 0·940 | 40·3 |
| NQ 150 | 0·758 | 28·5 |

Table 2

Compositions and physical data of some Propellants, fired in CV

| | AN 150 | WM 150 | T—28 Cord 150 |
|---|---|---|---|
| Nitrocellulose Type B | 55·85 | 65·12 | 67·07 |
| Nitroglycerine | 25·82 | 29·14 | 25·17 |
| Carbamite | 4·85 | 1·92 | 5·81 |
| DNT | 9·60 | — | — |
| Mineral Jelly | 3·95 | 3·58 | — |
| Potassium Nitrate | 0·89 | — | 0·75 |
| Barium Nitrate | — | — | 0·91 |
| Calcium Carbonate | — | 0·25 | — |
| Volatile matter | 0·44 | 0·85 | 1·0 |
| Diameter (cm) | 0·394 | 0·363 | 0·366 |
| Length (cm) | 12·7 | 12·7 | 12·7 |
| Density (g/cm³) | 1·533 | 1·573 | 1·600 |
| Covolume (cm³/g) | 0·973 | 0·921 | 0·924 |
| Rate of burning coefficient cm³/sec. kg $\beta_1$ | 0·0134 | 0·0204 | 0·0216 |

Rate of burning at each pressure is computed by :

$$r = \left(\frac{dP}{dt}\right) \left(\frac{1 + b - b\,\phi}{P_m + bp}\right) \left(\frac{D}{\sqrt{(1+\theta)^2 - 4\,\theta\,\phi}}\right) \tag{10}$$

where,

$$b = \frac{\left(\eta - \frac{1}{\delta}\right)\triangle}{1 - \eta\,\triangle} \tag{11}$$

$$\triangle = \frac{C}{V} \tag{12}$$

and

$$\phi = \frac{(1+b)\,P}{P_m + b\,P} \tag{13}$$

(11) and (12) are by definition and equations (10) and (13) are derived from (4) and (5) and the loading conditions.

The force constant is computed from :—

$$F = P_m \left( \frac{1}{\triangle} - \eta \right) \tag{14}$$

It should be noted that the $P_m$ is the cooling corrected $P_m$.

Values of $r$ and $P$ are plotted on a suitable graph and after omitting points which are obviously in error equations (1), (2) or (3) are fitted by the method of least squares to the $r$—$P$ data and the equation which gives the best statistical fit is accepted to represent the pressure range under consideration. For this least square fitting the $P$ value should be preferably the recorded $P$ value. It is also kept in mind that the accuracy of closed vessel for absolute firings is not better than $2 \cdot 5\%$ under the best conditions. The resul s are confirmed by carrying cut closed vessel firings at a number of other loading densities.

Such low pressure closed vessel firings have been carried out at ERDL on some conventional propellants. Their compositions and physical data are given in Table 2. Their rates of burning vs pressure graphs are given in Fig. 2. They represent cases where eqn. (2) is the best desirable fit. For carrying out the computations, suitable computer programs in AUTOMATH 400 (FORTRAN II) Language for use in any HONEYWELL 400 mod II computer are available at ERDL. Further work is being carried out on Arrow, PZS and M 7 compositions and also on a recoilless gun propellant T-28.

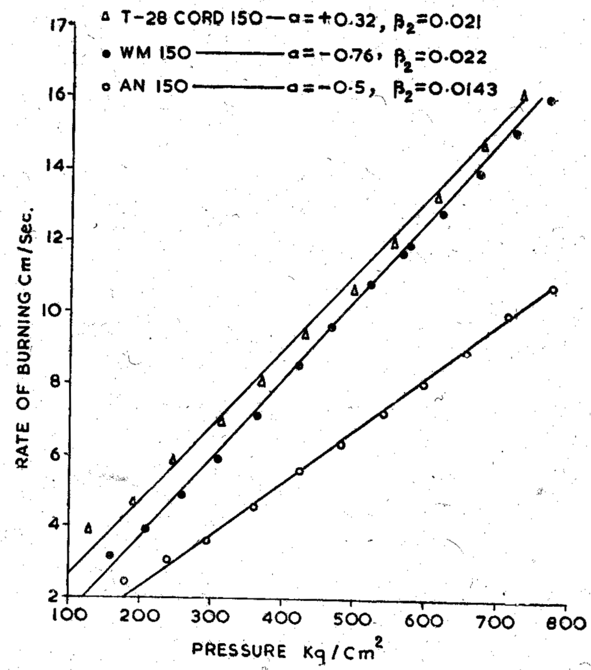


Fig. 2—Rate of burning Verses pressure for closed vessel firings of some conventional propellants at low pressure

This work was carried-out under the advice and guidance of Dr. S.K. Sinha, Director, ERDL. The assistance rendered by the Instrumentation group, ERDL for carrying out the closed vessel firings and by Mrs. Suneela Patgaonkar for the measurement of the records and the preparation of the computer coding forms and graphs etc., is gratefully acknowledged.

## REFERENCES


1. Charles Lenchitz, Rodolf, W. Velicky & Lester, Shulman, 'A Novel Thermocouple Method for the Rapid Determination of Strand Burning Rates' (Picatinny Arsenal Technical Memorandum No. 1724), 1965.
2. Hodge, D. L. & Pape, R., 'The Strand Rate Bomb as Control Method in Rocket Propellant Manufacture', (ERDE Technical Memorandum No. 8/M/55, UK).
3. 'Strand Burning Rate Test Procedure' (Radford Arsenal Report, USA), 1958.
4. 'Closed Bomb Test Procedure' (Radford Arsenal Report, USA), 1959.
5. Flint. H. A., 'Closed Vessel Theory', (ARE Report, UK), 1954.
6. 'Internal Ballistics', (HMSO Publications), 1951, pp. 160-172.
7. Sivaramakrishnan, G., *Defence Science Journal, Sec. B,* 8 (1958), 180.
8. Corner, J., 'Theory of Interior Ballistics of Guns', (John Wiley and Sons, New York), 1950, p. 38.
9. 'Encyclopedia of Explosives and Related Items', (Picatinny Arsenal, Dover, New Jersey Vol. III), 1966, p. C 430.
10. 'Encyclopedia of Explosives and Related Items', (Picatinny Arsenal, Dover, New Jersey, Vol. III) pp. C 430-431.
11. 'Internal Ballistics', (HMSO Publications), 1951, pp. 54-55.
12. Vittal, D., 'Proceedings of the Non-linear Ballistics Seminar' (Held at IAT, Pune), 1975, p. 68.
13. Bofors, A. B., 'Analytical Methods for Powders and Explosives' (Noberlkrut, Sweden), 1960, p. 172.
14. Corner, J., 'Theory of Interior Ballistics of Guns' (John Wiley and Sons, New York), 1950, p. 114.
15. 'Internal Ballistics', (HMSO Publications) 1951, pp. 19-22.
16. Vittal, D., Proceedings of the Non-linear Ballistics Seminar (Held at IAT, Pune), 1975, pp. 72-74.