USE OF CLOSED VESSEL AS A CONSTANT PRESSURE APPARATUS FOR THE MEASUREMENT OF THE RATE OF BURNING OF PROPELLANTS

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A method for the determination of burning rates of propellants whose form function is unknown is introduced. The method consists of burning in the closed vessel, a known charge weight of the test propellant alongwith a known weight of a very fast propellant and recording the pressure-time curve. The fast propellant generates a known pressure which remains nearly constant during the burning of the test propellant whose web size is the only quantity required for the evaluation of its rate of burning. The test propellant burns at near constant pressure conditions just as in the strand burner technique. This method can be applied to any unknown propellant of any shape whose web size can be measured and very large webs also can be used. In addition, the measurement of the records and the computation are very simple.

NOTATIONS

A_m	Reciprocal of the vivacity of the fast propellant
C_1	Charge weight of the fast propellant
D_0	Distance burnt of the test propellant at time T_0
D_1	Web size of the fast propellant
D_2	Web size of the test propellant
F_1	Force constant of the fast propellant
f_1, f_2	Fractions of webs D_1 and D_2 respectively, burnt at any time t
f_{20}	Fraction of web D_2 of the test propellant burnt at time t_0
P	Pressure
P_0	Pressure at t_0
P_m	Pressure at t_m
$\overline{P}$	Mean pressure at which the test propellant burns
r_1	Rate of burning of the fast propellant
r_2	Rate of burning of the test propellant
t_0	Time at which the fast propellant is burnt out
t_m	Time at which the test propellant is burnt out
V	Volume of the closed vessel
β_1	Rate of burning co-efficient of the fast propellant
β_2	Rate of burning co-efficient of the test propellant
η_1	Covolume of the fast propellant

The rates of burning of propellants at different pressures are experimentally measured by the closed vessel technique,[1,2 & 3] in the pressure region of 73.6 MPa—294.2 MPa (750 kg/cm^2—3000 kg/cm^2), and by the strand burner technique [4,5 & 6] for pressures upto 19.6 MPa (200 kg/cm^2). Micro rocket techniques[7] can also be used for the lower pressure region. An extension of the closed vessel technique[8] for measuring the rates of burning in the intermediate pressure region of 9.8 MPa—78.5 MPa (100 kg^1/cm^2—800 kg/cm^2) was introduced in ERDL (Explosives Research & Development Laboratory, Pune) in 1975.

The ERDL method requires certain precautions for getting the correct results.

(*i*) The propellant should be extruded in cord form preferably of web approximately 2.5 mm.

(*ii*) The length/diameter ratio to be equal to or greater than 50.

(*iii*) If the above two are not possible, then the form function of the propellant grains must be accurately known, the accuracy of which greatly controls the accuracy of the calculated rates of burning.

It happens often that propellants, particularly for rockets, seat ejection cartridges, gas generators, etc. come in large, complex shaped grains. They may be of foreign origin, their method of manufacture may be unknown and it may not be possible to extrude the cord form grains required by the experiment. Their form function during burning may not follow theory, e.g. the case of 7-holed mutlitubular grains. In addition, it may not be possible to carry out their ignition and recording properly in the normal CV technique. To cope up with situations like these, the following method of using the closed vessel for burning the test propellant at near constant pressure conditions (instead of the pressure change from 0-P_{max} in the normal CV) has been developed at ERDL.

MATERIALS AND METHOD

The method consists of the burning of a known charge weight of the test propellant in pieces of large web size alongwith a known weight of a standard propellant whose burning is very fast compared to the test propellant. The pressure vs. time curve is recorded upto a little distance after the maximum pressure in the cooling region, which shows a typical record as depicted in Fig. 1.

Both propellants are ignited together and start burning simultaneously at 0 time. The fast propellant is completely burnt out at time t_0, when the test propellant is burnt through only a very small distance and under favourable conditions its contribution to pressure is negligible and P_0 represents mainly the pressure generated by the fast propellant. During this period and further also, there is continuous heat loss to the walls of the vessel which results in a rate of fall of pressure which can be calculated by Vittal method[9]. After t_0 upto t_m, the test propellant continues to burn to completion. If the ratio of the charge weights of the two propellants are adjusted properly, the rate of rise of pressure due to the burning of the test propellant nearly compensates the rate of fall of pressure due to the heat loss and the pressure remains nearly constant from t_0 to t_m at $P_0 - P_m$. Thus the test propellant burns at near constant pressure conditions as in the strand burner and in an atmosphere of propellant gases as in the normal closed vessel.

If the web size is known D_2, then the measurement of the time of burning $(t_m - t_0)$ enables the rate of burning to be calculated as $D_2/(t_m - t_0)$ at a mean pressure $\bar{P}$ in the region $P_0 - P_m$. A small correction has to be applied for the distance D_0 burnt during the first interval from 0 to t_0.

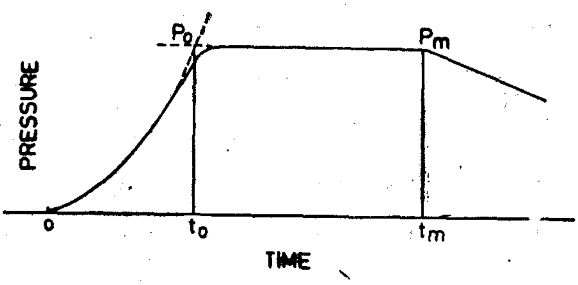

Fig. 1—Pressure-time record in CV of double propellant burning.

Assuming as a first approximation, the burning of the propellants to be represented by

$$r_1 = D_1 \frac{df_1}{dt} = \beta_1 P \quad (1)$$

$$r_2 = D_2 \frac{df_2}{dt} = \beta_2 P \quad (2)$$

(Suffix 1 denoting the parameters of the first propellant and suffix 2 those of the test propellant)

from (1) $df_1 = \frac{\beta_1}{D_1} \; P \; dt$

At $t = 0$, $f = 0$ and at $t = t_0$, $f = 1$ and $P = P_0$

Therefore

$$f = \frac{\beta_1}{D_1} \int_0^{P_0} P \, dt \quad (3)$$

and

$$\frac{\beta_1}{D_1} \int_0^{P_0} P \, dt = 1$$

i.e.

$$A_m = \int_0^{P_0} P \, dt = \frac{D_1}{\beta_1} \quad (4)$$

$\frac{\beta_1}{D_1}$ (the vivacity) is dependent only on the composition and the web of the propellant and therefore A_m can be conveniently found by carrying out a blank CV firing with the fast propellant alone and measuring the area under the P—t curve upto the maximum pressure of a blank firing record.

From (1), (2) and (4)

$$\frac{df_2}{df_1} = \left(\frac{\beta_2}{D_2}\right) \left(\frac{D_1}{\beta_1}\right) = \left(\frac{\beta_2}{D_2}\right) A_m \quad (5)$$

At $t = 0$, $f_1 = 0$ and also $f_2 = 0$, From (5), by integration,

$$f_2 = A_m \left(\frac{\beta_2}{D_2}\right) f_1 \quad (6)$$

Denoting the web fraction burnt at $t = t_0$ as f_{20} and f_1 being equal to 1 at that time

$$f_{20} = A_m \left(\frac{\beta_2}{D_2}\right) \quad (7)$$

i.e., the distance burnt at $t = t_0$

$$D_0 = D_2 \, f_{20} = A_m \, \beta_2 \quad (8)$$

Applying this correction D_0 to the web, the rate of burning of the test propellant is

$$r_2 = \frac{D_2 - D_0}{t_m - t_0} = \beta_2 \, \overline{P}$$

Where $\overline{P}$ is the mean pressure in the interval t_0 to t_m

As $\beta_2 = \frac{r_2}{\overline{P}}$, from (8) $D_0 = \frac{A_m r_2}{\overline{P}}$

Therefore

$$r_2 = \frac{D_2 - \frac{A_m r_2}{\bar{P}}}{t_m - t_0}$$

Rearranging

$$r_2 = \frac{D_2}{(t_m - t_0) + (A_m/\bar{P})} \quad (9)$$

This correction has been arrived at, using the linear law, for which it is accurate. If the propellants obey the index law, then the required integrations have to be carried out numerically, and the procedure is difficult and tedius. In such cases, the differences introduced into the correction term A_m/P can be reduced to negligible quantities by careful selection of the fast propellant such that its vivacity is very high compared to the vivacity of the test propellant and its pressure index is near to unity.

The charge weight of the fast propellant required to produce the pressure P_0, at which the rate of burning is calculated, is found by

$$C_1 = \frac{P_0 V}{F_1 + P_0 \eta_1} \quad (10)$$

The charge weight of the test propellant is found by carrying out a few test firings and the charge weight which gives a near horizontal curve from t_0 to t_m is the correct charge weight. Usually, it will be a small fraction of the charge weight of the fast propellant. In practice, for convenience in measurement, a slightly rising curve from t_0 to t_m is preferred and the mean value P is found out by a number of pressure measurements in the interval t_0—t_m. By this technique one CV firing gives one value of the rate of burning at one pressure. The firings are carried out at a number of different charge weights of the fast propellant to get a number of rate of burning values at different pressures.

The results of the technique, as applied to an experimental M7 type of propellant, two indigenous rocket propellants, A and B and an imported rocket propellant are given in Fig. 2 and 3. Their compo-

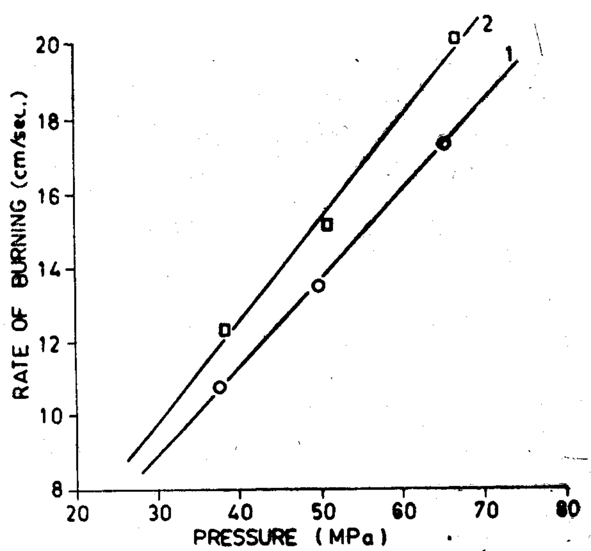

Fig. 2—M7 propellant; (1)—28·8°C, $r = 2{\cdot}17 + 0{\cdot}224P$; (2) 26·7°C, $r = 1{\cdot}85 + 0{\cdot}265P$.

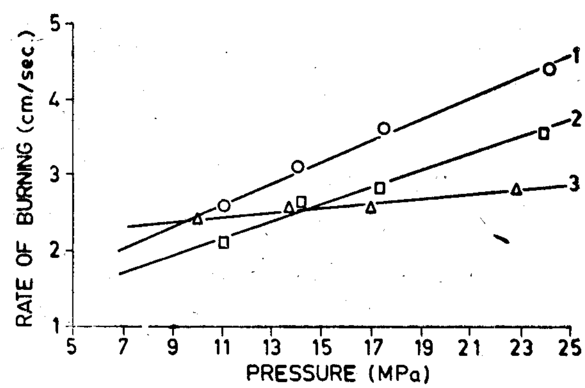

Fig. 3—Rates of burning of three typical rocket propellants (1) Indigenous rocket propellant B; 26·7°C, $r = 1.05 + 0{\cdot}141P$; (2) Imported rocket propellant : 26·7°C; $r = 0{\cdot}94 + 0{\cdot}109$ P; (3) Indigenous rocket propellant A; 26·7°C, $r = 2.13 + 0.0275P$.

TABLE 1

COMPOSITION OF THE PROPELLANTS

Ingradients	M7	Indigenous rocket propellant A	Indigenous rocket propellant B	Imported rocket propellant
Nitrocellulose	54.60	54.20	49.50	60.63
Nitrogen in NC	13.15	12.20	12.20	11.93
Nitroglycerine	35.50	36.70	41.50	27.26
Carbamite	0.90	5.50	4.00	—
Methyl centralite	—	—	—	1.30
DNT	—	—	5.00	—
DBP	—	3.60	—	—
Dimethylol nitroethane dinitrate	—	—	—	8.76
Carbolac	—	0.70	0.50	—
Carbon black	1.20	—	—	—
Candellilla wax	—	—	0.075	—
Calcium carbonate	—	—	—	1.84
K. cryolite	—	—	2.25	—
K. sulphate	—	—	—	0.21
K. perchlorate	7.80	—	—	
Lead salt	—	4.10	—	—

sitions are given in Table 1. A high vivacity, porous propellant in ballistite composition, was used in all cases as the fast propellant and the charge weights of ballistite *vs.* the mean pressure of the experiments are given in Fig. 4. These are given only to illustrate the type of results which can be obtained by this technique and not as a study of the performance of the propellants which require further extensive firings. Further work is in progress for the application of the method of different propellants and comparison of the results with the results of normal CV firings wherever possible.

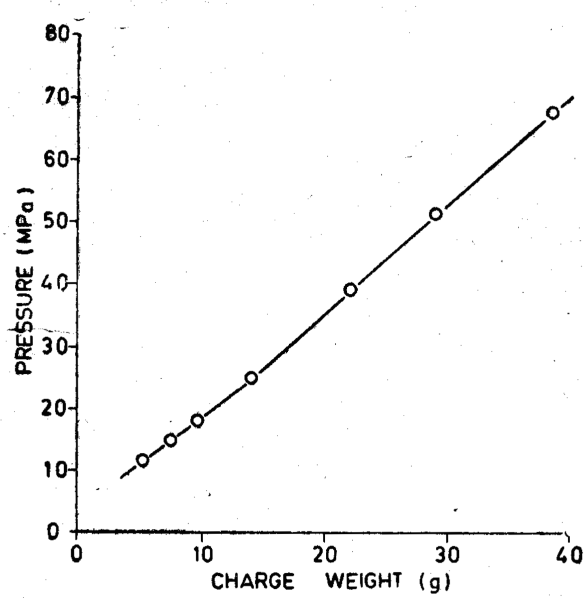

Fig. 4—Ballistic pressures.

As seen by the Eqn. (9), only the web size of the test propellant need be known. If the propellant is in the form of a very large rocket propellant grain, a small piece can be cut out from it, the smallest dimension of the piece can be measured as the web and the rate of burning can be evaluated. No inhibition of the propellant grain is necessary (as in strand burner) but already inhibited rocket propellant grain can also be evaluated by this method without removing the inhibition taking care only to measure the correct distance through which the grain will burn (as the web). The measurement of the P—t records is very simple and involves only two quantities, i.e., tm—t_0 and $\bar{P}$. The arithmetical work involved is negligible.

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REFERENCES

1. 'Closed Bomb Test Procedure' (Radford Arsenal Report, USA), 1959.
2. 'Internal Ballistics' (HMSO Publications, UK), 1951, p. 160—172.
3. SIVARAMAKRISHNAN, G., *Def. Sci. J. Sec B*, **8** (1958), 180.
4. 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.
5. HODGE, D. L. & PAPE, R., 'The Strand Rate Bomb as Control Method in Rocket Propellant Manufacture' (ERDE Technical Memorandum No. 8/M/55, UK).
6. 'Strand Burning Rate Test Procedure' (Radford Arsenal Report, USA), 1958.
7. BYRON, L. COCKRELL, 'Ballistic Evaluation of Propellants in Micromotors' Report No. S-49; (Rohm and Heas Co., Redstone Arsenal, Alabama, USA), 1964.
8. VITTAL, D., *Def. Sci. J.*, **27** (1977), 83.
9. VITTAL, D., 'Proceedings of the Non-Linear Ballistics Seminar (Held at IAT, Pune), 1975, p. 66—75.