CLOSED VESSEL TECHNIQUE FOR ASSESSMENT OF BALLISTIC CHARACTERISTICS IN QUALITY CONTROL OF PROPELLANT MANUFACTURE

by

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ABSTRACT

In order to assess the Ballistic performance of a propellant it is necessary to measure its following characteristics :

(*a*) Force constant, (*b*) vivacity, and (*c*) shape.

It is possible to determine (*a*) and (*b*) by the closed vessel technique which enables ballistic performance of the propellant in the gun to be estimated. It can be very usefully employed for quality control of propellant manufacture.

As more and more experience is gained in the closed vessel technique these tests have several other possible practical applications such as those

(*a*) for inspection of propellants, (*b*) for assessment of quality, (*c*) to reduce proof in guns, and (*d*) to check ballistics of a lot after long storage.

Introduction

Propellants form a group of explosives, whose speed of burning is governed by external pressure on their surface. This governability by external pressure allows their precise designing for each purpose. Propellants are made specifically for each propulsion device. Depending on the performance requirements, a wide range of shapes and sizes are current. They range from the tiny flakes or granules used in sports weapons, which are only a few thousandths of an inch thick, to the giant 'grains' many inches thick used in rockets and power cartridges. The precisions of performance expected of each also vary widely. But of all these, the propellants for guns form the most precise class, even today.

A good modern gun speeds its consecutive projectiles to an accuracy better than 1 in 1000. This accuracy is higher than that of the chemical analysis used today to control the quality of propellant used in the gun. Chemical composition of the propellant decides the total amount of thermal energy released by burning it. This thermal energy controls to a large extent the ballistics of the projectile. This control of chemical compositon by analysis is the most precise control that the propellant manufacturer has on his product, today. In normal gunfire, a variable fraction of the thermal energy released ranging about a third is transformed into kinetic energy of the projectile, by the expanding powder gases. The exact value of the above fraction, depends on the rapidity of burning of the propellant in the gun. Unfortunately, this fraction is neither as precisely controllable nor as repeatable during propellant manufacture, as the chemical composition. The rapidity of burning or vivacity of propellant, varies from lot to lot of manufacture. In the gun, these variations in vivacity, produce variations in velocity and even larger variations in pressure. If the vivacities are controlled during manufacture, to the same extent as composition of propellant, very much higher precision in ballistics would be possible. The Ordnance Board in U. K. have expressed the opinion recently, that the accuracy of modern gunfire is limited mainly by the precision of the propellant used in the ammunition. They have stated that a closed vessel control of the vivacities would reduce this limitation significantly.

Chemical kinetics of propellant burning is, even today, an abstruse subject. Fairly wide and often inexplicable changes in burning rates are known to occur in the same process of manufacture. Sometimes, these are traceable to seemingly trivial changes *e.g.* in sources of raw material, processing times or even weather. Changes upto twenty per cent in burning rate, have been noted at TDE (ME), Kirkee, for similar propellants made at different times. Similar results have been recorded at ARDE, UK also. These variations are not explicable by any of the current theories of burning rates. After decades of experience, with these inexplicable ballistic variations, the manufacturers and users of gun propellant have developed an attitude of extreme caution and conservatism with regard to propellant manufacture. Consequently the propellant manufacture is now an art—an art of meticulous repetition of all details of manufacture. It is an open question, whether all the details of manufacture specified today, are critical or even necessary for steady ballistics. Unfortunately so far, any attempt to find this out, had to face the delays and expenditure of actual gun trials—tens of thousands of rupees—as no simple test for performance was known. True, even in Moissans' time, closed vessel firings were tried out for fast and economic assessment of propellant performance. But the poor repeatability of propellant manufacture and the insufficient accuracy of closed vessel measurements at that time, did not allow much progress. Actual firing in the gun was the only method of proving propellants sufficiently accurately.

Normally, gun proof is carried out at another establishment equipped for it, often at considerable distance from propellant factory. Consequently, there is considerable delay from the time of manufacture of propellant, to the time when its ballistic data become available. This makes alterations to or experiments with propellant manufacture very difficult, time-consuming and costly. If the processing time of propellant is small and gunproof is carried out at the propellant factory, improvements in manufacture can be expected to be rapid. This is actually the case, in the factories catering to small arms and sports weapons. The progress in this field is indicated by the bewildering variety of makes, shapes, types and compositions available in propellants for small arms, inspite of the difficulties in manufacture due to the smaller propellant size and difficulties in proof due to the faster gun action. On the other hand, it is common practice, even today, for thousands of pounds of a well established type of gun propellant to be rejected, months after manufacture, because of unsuitable ballistics obtained in gun proof. In such a case, the manufacture of propellant is left helplessly guessing both the reasons for the failure and methods for its correction. At the beginning of last war, these difficulties stood in the way of the gigantic programmes of propellant production in USA. The manufacturers (in particular Du Pont) were perforce, led to develop the technique of the modern laboratory assay of propellant ballistics by closed vessel. In essence, this US closed vessel test, compared the test propellant against a standard propellant for force and vivacity. As variations in force and vivacity (or quickness) are the main characteristics that cause ballistic variations between lots of the same propellant, it was soon proved and accepted that gunproof was redundant, if variations in these relative values (called R.F.=Relative Force and R.Q. = Relative Quickness) are within specified limits.

The closed vessel is a laboratory apparatus. It is considerably more economical than the gun in material, man hours and space requirements. Housed in the propellant factory, it can produce results much earlier than the gun. The propellant manufacturer with his own closed vessel, is thus freed from the delays and vagaries of the gun proof data obtained from another establishment. Also, because of its rapidity and all round economy, he can use his closed vessel, just as assuredly as his micrometer gauge, to directly control the quality of his product, and bring it within specification limits. Better still, he can use it with equal ease, to develop new products or processes to suit even better specifications. All this simplification and rationalisation is justifiable theoretically also, as the propellant characteristics Force, Vivacity and Form Factor can be shown to be the main variables that control propellant ballistics. The determination and accurate comparison of these characteristics is the basis of the current closed vessel technique of propellant assay.

Closed Vessel Technique

The current design of closed vessel is shown in Fig. I. This is an accurately dimensioned, quantitatively sealable, steel chamber, in which an aliquot sample of the propellant is burnt under constant volume conditions. An accurate piezo-electric gauge, a wide band DC amplifier, a cathode ray oscillograph and a suitable camera are used to record the pressure-time or other derivative curves. The quantity of propellant exploded in the vessel each time corresponds normally to the effective density conditions in the gun, when the propellant charge in the ammunition is just burnt. For modern guns, this is about 0·2 . The piezo-electric gauge has good high frequency response and allows recording of the fastest pressure changes occurring in these explosions. Some typical pressure time records are given in Fig. II. The dotted line is a time scale in milliseconds. The dots are produced by flashes from a thyratron, controlled by a 1000 cycle tuning fork and recorded at the same time as the pressure signal. The horizontal calibration lines are made immediately before the explosion by calculated potentiometer controlled voltages. The explosion pressure rises approximately exponentially at first and then fairly rapidly steadies upto a maximum. Cooling of the gases by the chamber walls, causes a gradual fall afterwards. Small corrections for this cooling are applied in practical measurements for getting the uncooled maximum pressure. The wide differences in rapidity of burning between the three propellants is evident, although these are far from the extremes of

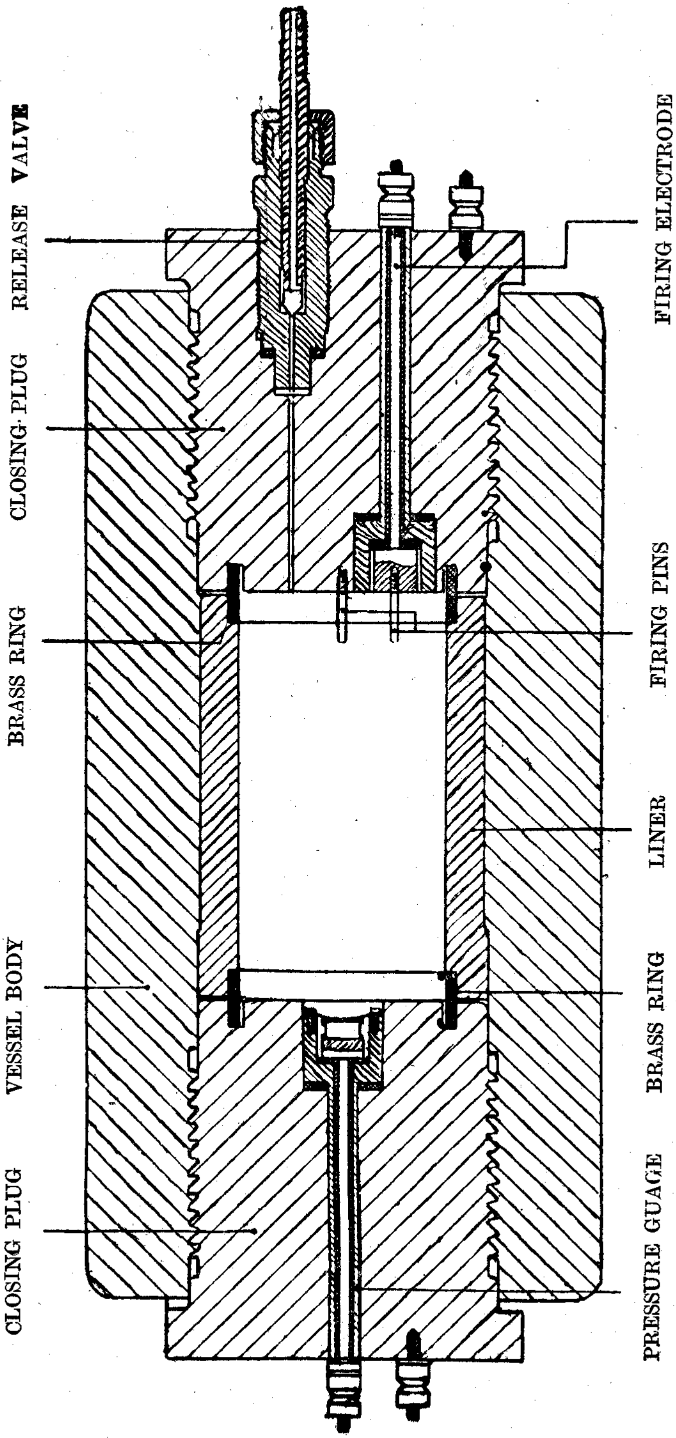


FIG. I
CLOSED VESSEL.

PRESSURE TIME CURVE

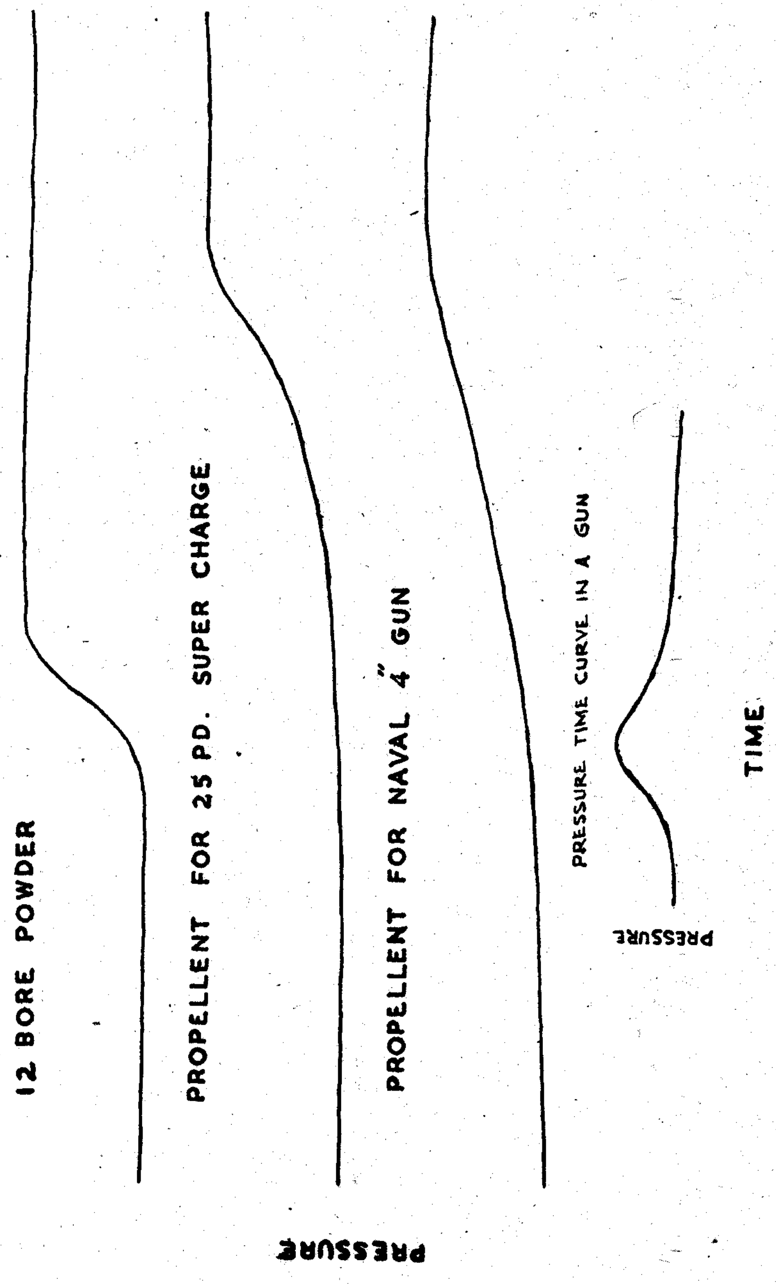


Fig. II

rapidity, normally met with in ammunition. The bottom-most curve is a corresponding pressure-time record in a gun, with the time marks in ten thousandths of a second and calibration steps for pressure. The maximum pressure in the gun is more closely connected with the maximum rate of pressure rise in the closed vessel than the maximum pressure itself. The rates of pressure rise—time records in the closed vessel have much more detail and diagnostic value than pressure time curves.

Figs. III and IV give some typical $\frac{dp}{dt} - t$ closed vessel curves for some of the various shapes of propellants in service· These curves are particularly useful for finding 'effective' Form Factors for various propellant shapes. It would be noted that all these curves show an almost exponential rise, a maximum of varying sharpness and a return to base of varying steepness. Propellants with higher form factors show blunter maxima and lower steepness of return to base. For example, for a perfect tubular propellant, theory indicates, that the curve would have an exponential rising part, as the pressure builds up in the closed vessel, followed by a perpendicular fall to base as all the propellant is burnt out 'simultaneously'. The steep fall would leave a sharp maximum on the record. As seen in Fig. III, the practical tubes do not show this sharpness of peak and steepness of fall. These departures from expectation vary with the composition and quality of propellant. It can be shown, that grain to grain differences in size, structure and uniformity of shape, all contribute to blunt the peak and reduce the steepness of fall in these curves. Measured in terms of θ, the effective form factor, these effects in tubes, range from $0 \cdot 05$ to $0 \cdot 25$ in different propellants. Most of the values recorded range about $\theta = 0 \cdot 20$ and is probably an experimental justification for the empirical value $\theta = 0 \cdot 2$ used in many ballistic computations, instead of the geometric value $\theta = 0$.

Similar increases in θ are used by ballisticians for multitube propellant. A value $\theta = 0$ instead of $\theta = 0 \cdot 2$, along with an increased vivacity is in general use. Experimental values of θ for multitube range from $\theta = 0 \cdot 15$ to $\theta = 0 \cdot 35$. The average ballistic effects of these are in approximate agreement with the results of empirical values assumed by the ballisticians. For cord and slotted tube propellants, the ballisticians use the geometric form factors. The arguments about heterogenieties in tube and multitube and their effect on increasing θ exist for the cord and slotted tube also. In fact, experimental values for slotted tube indicate values of $\theta = 0 \cdot 30$, about $0 \cdot 15$ above the geometric value. These are anomalies requiring investigation. The determination of effective 'form factor' is a virgin field in experimental ballistics. It is of particular interest in assessing effects of blending different lots and for uniformity checks inside single lots.

The $\frac{dp}{dt} - t$ curves from closed vessel are of great use in measuring the characteristics of small arms propellants. Some of these are given in Fig. V. Modern small arms propellant manufacture is an art, not amenable to easy mathematical analysis. They are made to varying porosities, wide variety of grain shapes and moderated to a designed non-homogeniety of composition in each grain. Their closed vessel curves show in all cases, the usual exponential rise to a maximum. But the finish appears to be always a Gaussian Error curve. The latter is to be expected from the wide grain to grain differences and the designed heterogeniety inside each grain. Thus, despite the extremely wide variety of shapes, GEOMETRIC vs PRACTICAL FORM FACTOR, INDIGENOUS FLASHLESS-NON-PICRITE PROPELLANT

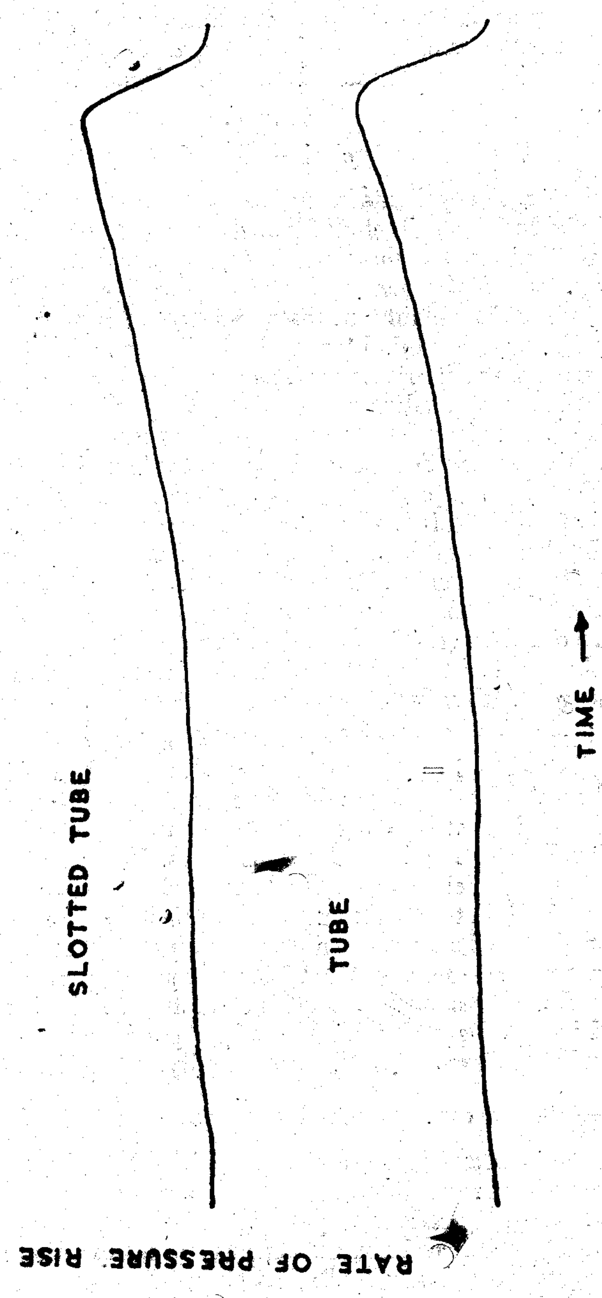


Fig. III

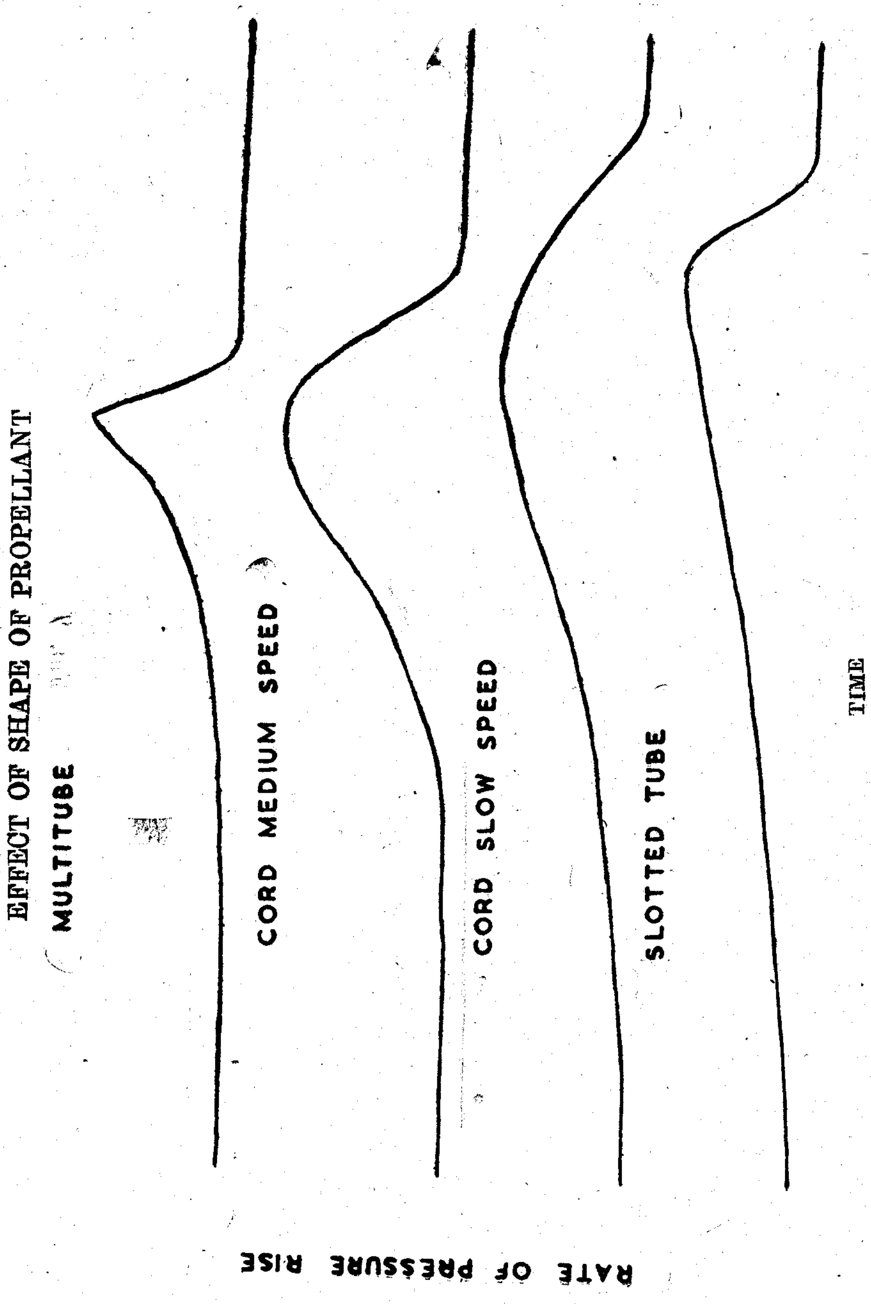

EFFECT OF SHAPE OF PROPELLANT
MULTITUBE
CORD MEDIUM SPEED
CORD SLOW SPEED
SLOTTED TUBE
TIME
RATE OF PRESSURE RISE

FIG. IV

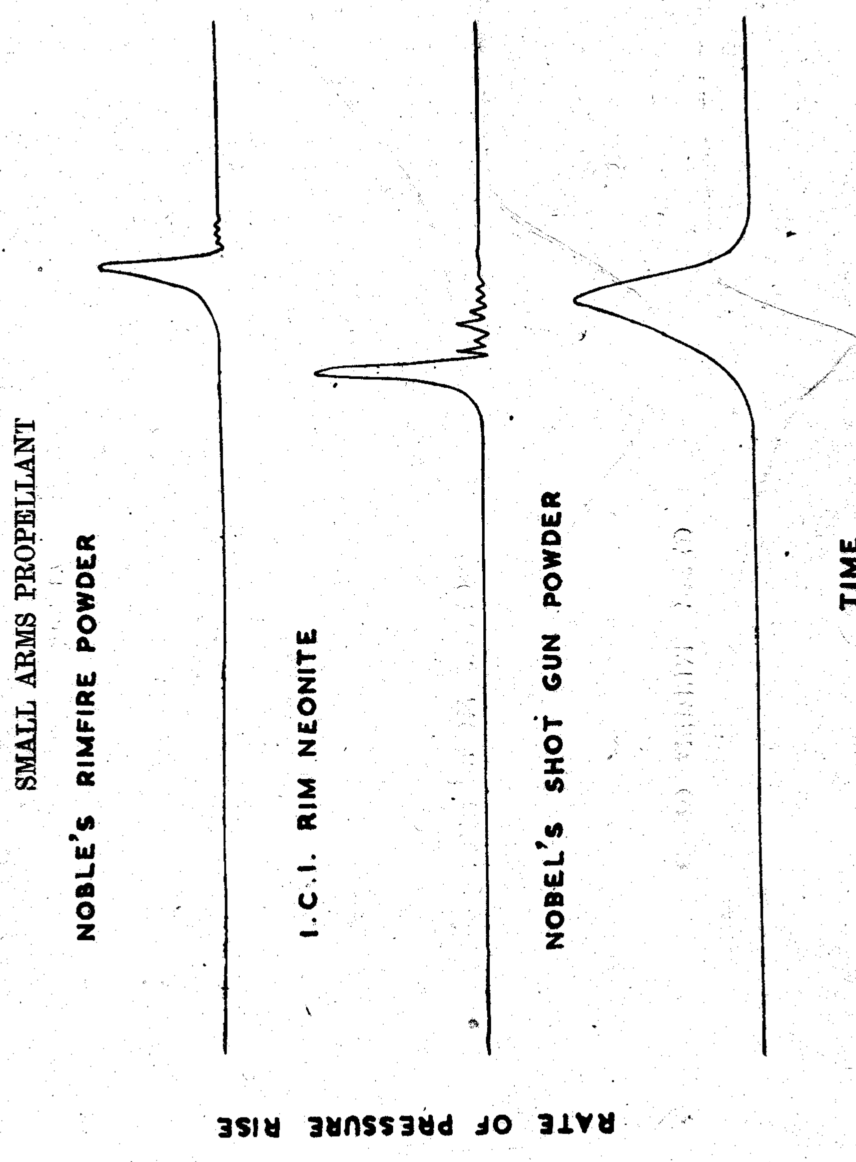

SMALL ARMS PROPELLANT
NOBLE'S RIMFIRE POWDER
I.C.I. RIM NEONITE
NOBEL'S SHOT GUN POWDER
TIME
RATE OF PRESSURE RISE

FIG. V

structures and compositions available in small arms propellant, their statistical distribution appears to control their burning characteristics and allows some rationalisation of their measurement for ballistic assessment. The maxima in these $\frac{dp}{dt} - t$ curves show a close parallel with the 'vivacity' of gun propellants and corresponding correlation with small arms ballistics. The mathematical development of this field is a very urgent problem.

Equations for Propellant Burning in Closed vessel

The basic equations used for analysing propellant burning in closed vesses have a close parallel to the basic equations of Internal Ballistics. It is this similarity of equations that allows the considerably generalised ballistic assessment from closed vessel data. The basic equations of closed vessel are the followings:

(*i*) *Equation for Burning of the Propellant Grains*

$$D \frac{df}{dt} = \beta P \quad \ldots \quad \ldots \quad \ldots \quad (1)$$

where D and f are the web size and its fraction burnt and β the 'effective' linear burning rate of the propellant in the pressure range of interest. It is to be noted that the β as above defined, does vary somewhat with the range of pressures used. This is the main reason for duplicating the gun pressure conditions in the closed vessel as stated previously.

(*ii*) *Form Function of Propellant Grains*

$$\phi = f(1 + \theta - \theta f) \quad \ldots \quad \ldots \quad (2)$$

where ϕ is the fraction of charge burnt and θ the 'effective' form factor. The equation (2) assumes 'long' grains and is not strictly applicable to short S. A. propellants. This is one of the major difficulties in mathematical analysis of S. A. propellant ballistics.

(*iii*) *Equation of state of powder gases*

$$P[V - \eta c + (\eta - \tfrac{1}{\delta})(1 - \phi) c] = nRT_0 C\phi = FC\phi \quad \ldots \quad (3)$$

where P is the pressure, V the volume and η the co-volume of powder gases, R the gas constant, n the number of moles of gas produced per unit mass of burnt propellant. C is the mass, δ the density, T_0 the flame temperature, F the force constant and ϕ the charge fraction burnt of the propellant.

When the propellant charge is fully burnt, the maximum pressure P_m is attained. Then,

$$P_m (V - \eta C) = FC \quad \ldots \quad \ldots \quad \ldots \quad (4)$$

Neglecting some correction terms, the above equations reduce essentially to

$$\text{Force constant } F = P_m \left(\frac{V}{C} - \eta \right) \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (5)$$

$$\text{and Vivacity } \quad \frac{\beta}{D} = \left(\frac{dP}{dt} \cdot \frac{1}{P} \right) \frac{1}{P_m} \left(\frac{d\phi}{df} \right) \quad \ldots \quad \ldots \quad (6)$$

The pressure time records as in Fig. II allow calculation of $\frac{\beta}{D}$ from (6) if the absolute values of Pm and $d\phi/df$ are known. $d\phi/df$ values involve knowledge of effective form factor θ.

And, these are, as seen earlier, only approximately known. However for similar propellants at equal charges C, the

$$\text{Relative Force} = \frac{P_m \text{ of Test Propellant}}{P_m \text{ of Standard Propellant}} \quad .. \quad .. \quad (7)$$

$$\text{Relative Vivacity} = \frac{\left(\frac{dP}{dt} \cdot \frac{1}{p}\right)\frac{1}{P_m} \text{ of test propellant}}{\left(\frac{dP}{dt} \cdot \frac{1}{p}\right)\frac{1}{P_m} \text{ of standard propellant}} \quad (8)$$

accurately and independent of actual form function. This is the basis of the current procedure in UK and USA, to avoid the errors of absolute values in vivacity. Practical ballisticians would find in this method, a close parallel with their current method of converting 'as fired ballistics' to 'corrected ballistics' by using the 'as fired' ballistics of the standard round as a reference point. This would be clearer by a parallel discussion of the equation of Internal Ballistics of Guns.

Basic Equation of Internal Ballistics of Guns

In their simplest forms, these are

(*i*) *Equation of Burning of Propellant Grains*

$$D \frac{df}{dt} = \beta P \quad .. \quad .. \quad .. \quad (9)$$

where D, f, β and P have the same meaning as in the closed vessel equation (1).

(*ii*) *Form Function of Propellant Grains*

$$\phi = f(1 + \theta - \theta f) \quad .. \quad .. \quad .. \quad (10)$$

This is also similar to (2), except for minor increases in θ due to 'erosive' burning of grains in high velocity guns.

(*iii*) *The Equation of State of Powder Gases*

$$P(V - bA) = nRTC\phi \quad .. \quad .. \quad .. \quad (11)$$

where b is a small correction term involving co-volume of powder gases and density of propellant, V—bA is the effective volume of powder gases behind the shot, A the area of cross section of bore, and T the average temperature of powder gases. Other terms have the same meaning as in (3).

(*iv*) *The Equation of Motion of Projectile*

$$m \frac{dU}{dt} = mU \frac{dU}{dX} = PA \quad .. \quad .. \quad .. \quad (12)$$

where m is the effective mass of projectile, U its velocity, X the effective length of gas column and P the effective pressure behind shot and A the area over which it is acting.

(*v*) *The Equation of Energy.*

Neglecting losses due to friction, heat conduction etc. this is

$$\tfrac{1}{2}mU^2 = \frac{FC\varphi - PA(X-b)}{\gamma - 1} \quad .. \quad (13)$$

where γ is the ratio of specific heats.

These equations reduce to the usual forms

$$\text{Velocity } U = \frac{AD}{m\beta} f = U_b f \quad .. \quad (14)$$

where U_b is the velocity at 'burnt' point.

$$\text{Pressure } P = mU_b^2 f \frac{df}{dx} \quad .. \quad (15)$$

The usual central equation of ballistics becomes simply

$$(X - b)\frac{df}{dx} = \frac{FC}{mU_b^2}(1 + \theta - \theta f) - \frac{\gamma - 1}{2} \quad .. \quad (16)$$

Equations (14), (15) and (16) lead normally to a complete ballistic solution.

Examination of the above equations reveal two obvious, but important and often disputed points:

(*a*) Two of the propellant characteristics, β the burning rate and D the web size, enter these equations only as their ratio β/D (called Vivacity). Therefore, their individual values are immaterial for ballistics. It is possible to choose a D for any practical value of β to get the required β/D. The older insistance of 'correct size' of propellant has to be modified now as 'correct vivacity'. This is important, because as already stated before, wide variations in β occur under normal factory conditions, sometimes even without any obvious reason for it. Also, the measurements of 'D' for control, are extremely limited in accuracy, as the grain shapes are rarely of the specified geometry or uniform; and even the 'roughness' of surface of the propellant grains influence these measurements.

β/D Values from C.V. are more precise.

(*b*) The Force Constant F and charge C enter the equations only as their product FC. It is clear, therefore, that for any practical F, a satisfactory C can be got, limited only by the physical capacity of the gun chamber. Specifically, no ballistic distinction exists within the above limits, between propellants of differing chemical composition or calorific value, if FC is kept constant.

The equations (14), (15) and (16) also imply, that if two propellant charges with equal FC, β/D and θ are fired in any gun, the ballistics would be equal. Fig. VII gives the $\frac{dp}{dt}$ —t curves for three such propellants. The close similarity in the main shape of the curves is evident. This is the quantitative basis of the closed vessel technique today for ballistic assessment of similar propellants, whether it is for (*a*) quality control of production at the factory, (*b*) deterioration due to storage at reserve depots (*c*) matching of new indigenous propellants with imported ones (*d*) investigating abnormal ballistics in accidents or (*e*) evaluation of a new process or material for propellant manufacture in the factory for a required improvement in performance.

The required values of F, β/D and θ are determined easily by closed vessel firings. But, as shown under equation (1), various limitations exist (due mainly to our ignorance of the precise burning laws) in using these data for absolute values. These limitations reduce the accuracy of absolute measurements in closed vessel, today, to a few per cent. This is too low for most of the important problems in service. Similar uncertainties in absolute values exist, in routine gunproof also. There, it is circumvented, by using the ballistic data for a similarly fired standard round of ammunition, as reference values, and noting only the comparative ballistics. A parallel technique in closed vessel improves the accuracy of its measurements considerably. In this method, only the small differences in F, β/D and θ between almost equivalent propellants are measured. These measurements are accurately and unambiguously carried out from closed vessel oscillograms. They are almost free from the limitations of the formula of (1) and (2). This method of differences, has a wide and important field of application in service problems. The differences in F, β/D and θ can be computed by monomial methods to corresponding differences in ballistics. This indirect method has a higher precision than direct gun proof, as the closed vessel data have a higher precision and short-time repeatability. The following applications are chosen mainly to show the width of field open to this method of relative ballistic assessment and its importance to current service problems.

Applications

Propellant Production at Constant Ballistic Level

Of the two factors F and β/D involved in this problem, chemical control is sufficiently satisfactory for controlling F. Control of vivacity (β/D) at the blending stage by judicious mixing of high and low vivacity pre-blends had been adopted in U.K. Relative measurements of pre-blend β/D's by closed vessel is proposed for this. Fig. VI gives the data for a number of lots of a new naval propellant produced at CFA, watched and controlled by closed vessel. The variations in ballistic level of current lots of the propellant, are too small and difficult to detect by gunproof. This should be of interest to authorities manufacturing and inspecting propellants.

Ballistic Life of Ammunition

Propellant deterioration in storage, is one of the main causes of limiting the ballistic life of ammunition. Chemical stability of propellant, is often confused with its ballistic serviceability after ageing. The chemical stability can be an indication of stable force constant (F). The vivacity (β/D) variations are not indicated in chemical stability tests. Accelerated storage of the ammunition, at controlled warm conditions (about 50°C), is used for assessing chemically stable life of propellants. Similar storage is used to assess also changes in propellant ballistics, expected after long storage. The closed vessel is particularly adopted for this work, as it has only to compare two samples of the same propellant, one stored at 50°C and the other at normal magazine conditions. The significant differences in vivacity, normally observed in such tests, are barely two or three per cent. And these are observed in normal propellants, after months of accelerated storage. Normal gunproof is not accurate enough to measure this. Also, considerably more ammunition and space in the accelerated storage huts, would be required for the gunproof method. Closed Vessel is much more economical in this, as often, only a few ounces of propellant are required

GRAPH SHOWING THE SIZE, WEIGHT PER 100″, A. C. W. ADJUSTED CHARGE PRESSURE AND VIVACITY OF NAK/S 164—048 BATCHES

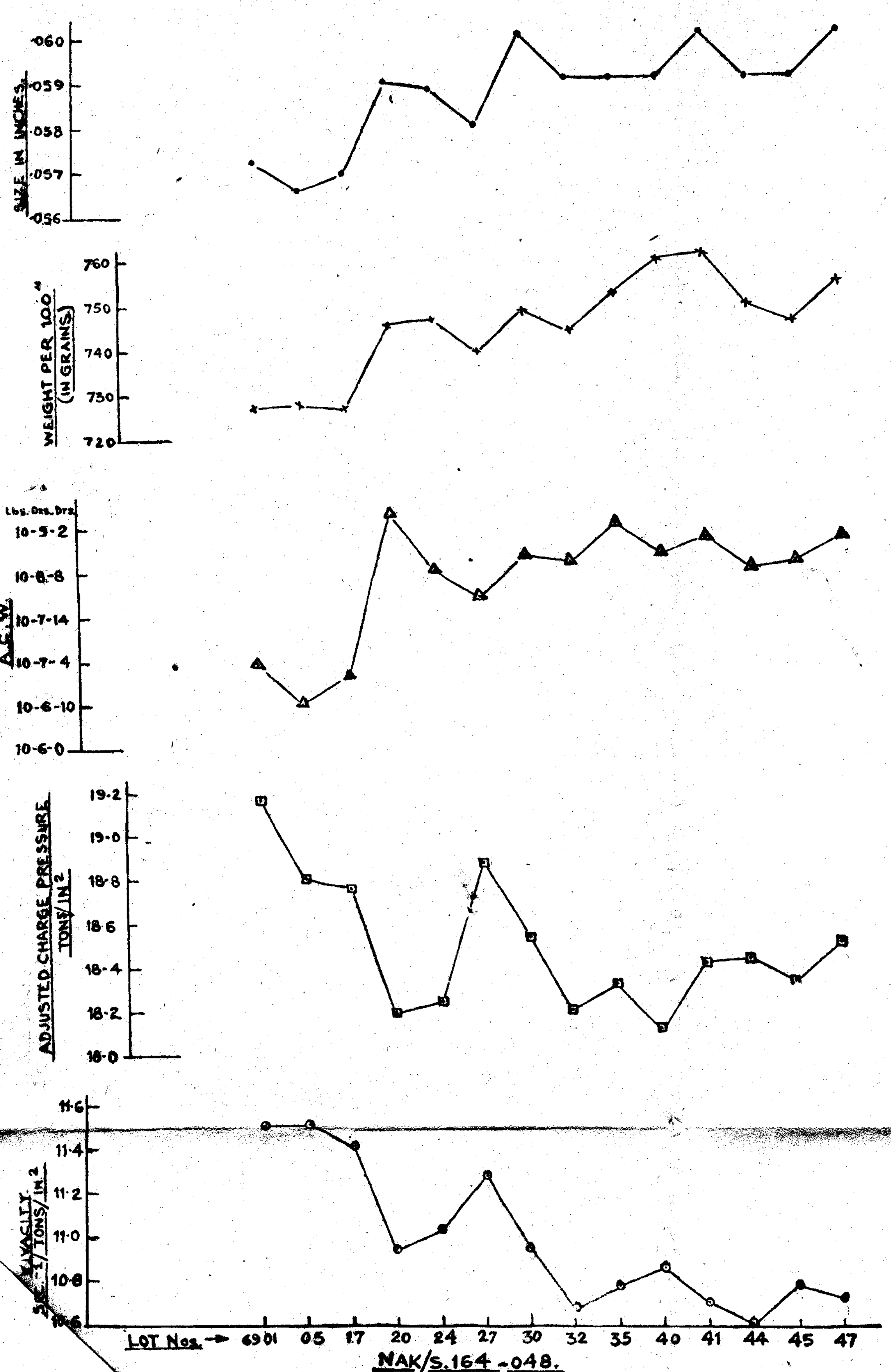


FIG. VI

EQUIVALENT PROPELLANTS OF DIFFERENT COMPOSITIONS/PROCESSES

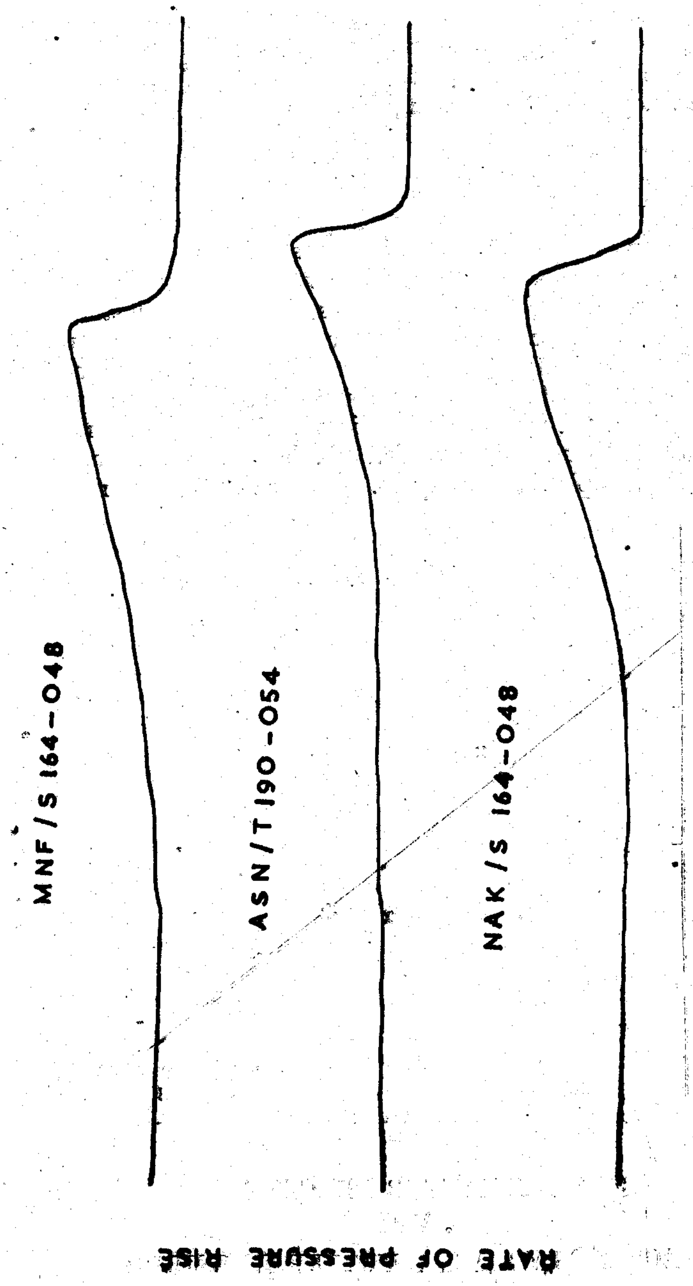
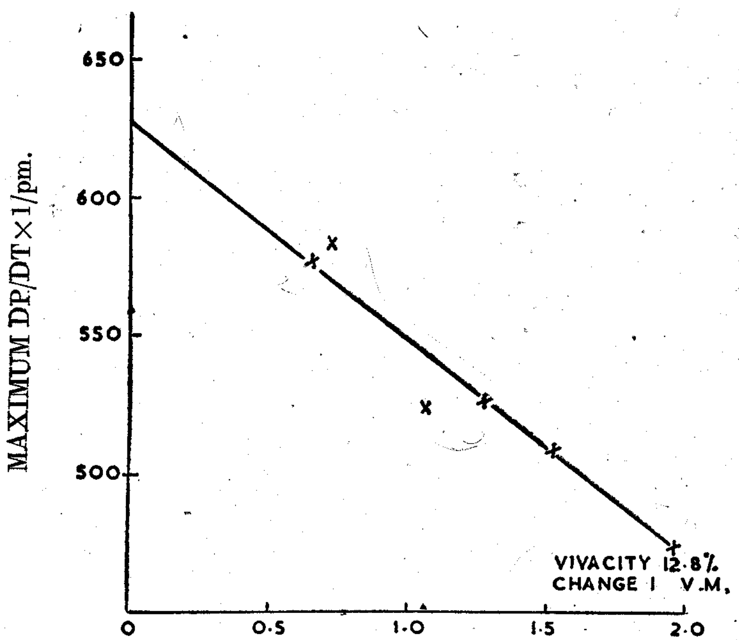


FIG. VII

for the tests. This method of assessing ballistic life of propellant, is as useful in purchases of new ammunition, as in assessing the residual life of old ammunition in stock. In the former case, it gives a rapid assessment of the period for which the propellant in the ammunition can be depended upon for performance. In the latter case, the method gives a rapid, economical method for assessing the residual life, so that timely condemnation of old stocks and economic planning of new production can be arranged. This should be of immediate interest to the authorities provisioning ammunition.

Investigation into Abnormal Ballistics and Accidents with Ammunition

In problems connected with Abnormal Ballistics and Ammunition Accidents, it considerably simplifies analysis, if the propellant behaviour is independently checked up without the weapon. The closed vessel comparison of the suspected propellant with a satisfactory one, is an easy and precise method for this check-up. In a particularly persistent series of sporadic ballistics, in some anti-tank ammunition, the closed vessel method was found very successful. Chemical analysis and stability of the propellant from various lots of this ammunition had revealed no significant abnormality. Closed Vessel firings were then carried out. They revealed wide variations in vivacity, upto fifteen per cent between different lots. Examination revealed volatile matter variations up to one per cent. Fig. VIII is a plot of vivacity vs. volatile matter of various lots of



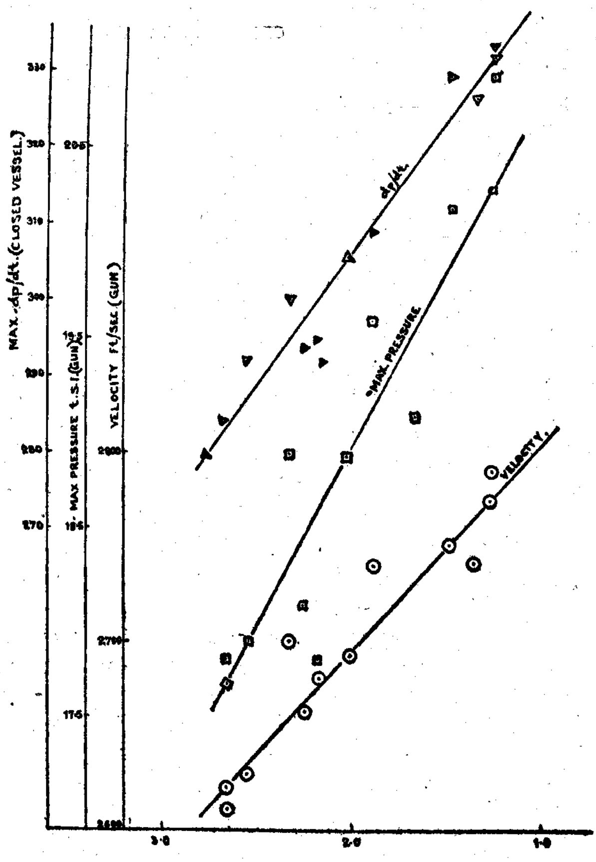
VOLATILE MATTER PERCENT

Fig. VIII

VIVACITY VS VOLATILE MATTER IN FNH/DB

propellant. As the correlation coefficient agreed with expected values, a confirmatory firing in the gun was arranged with two lots of ammunition, one with a low volatile matter content (dry) and the other with higher (*i.e.* normal) volatile matter content. The former (Dry) lot gave as expected, dangerously high ballistics. The latter (Normal ?) rounds gave widely erratic ballistics varying with each round. One ounce of the charge was removed from each of these rounds and the ballistics recorded, for each round separately. The charges removed from each round were also separately tested for volatile matter content and vivacity. The results are plotted in Fig. IX. The close correlation between the widely varying volatile matter content, muzzle velocity, pressure and vivacity in these rounds from a single box of ammunition, tell their own tale very clearly. The rounds have dried out to varying extent in storage. It was evident that none of the rounds in any of the lots could be relied on for safe performance. This should be of interest to the authorities investigating ammunition accidents.

PROPELLANT FNH/DB EXTRACTED FROM 37 MM. AMMUNITION



V. M. CONTENT PERCENT

FIG. IX

VARIATION IN BALLISTICS VS VARIATION IN VOLATILE MATTER CONTENT

Igniter Requirements in Ammunition Design

This is a little known, but important and difficult problem in these days of cool propellants and subzero requirements. The normal criterion for igniter sufficiency, is satisfactory firing performance under the required weather conditions. With sufficient igniter, the firing interval and ballistics are normal and steady. A parallel result is noticed in closed vessel firings. With insufficient ignition, the ignition delay is longer and variable. And the oscillograms vary from round to round. In a particular instance, a U.K. propellant for a machine gun ammunition; persistently gave inexplicably low ballistics compared to one U.S.A. propellant. The force and vivacity of U.K. propellant were found to be sufficiently higher than those of U.S.A. propellant, to give at least 10 per cent extra ballistics. A check up of igniter requirements of the propellants (by closed vessel) revealed the higher igniter requirement of the U.K. propellant. A changed igniter cap gave on trial, the expected higher ballistics with U. K. propellant. This method is more economical and expeditious, particularly for low temperatures, as closed vessel is more easily maintained at low temperatures, than guns.

New Processes of Propellant Manufacture

New propellant processes take years to establish if gunproof is necessary to follow every modification. This procedure is costly, as for each variant, hundreds of pounds of propellant and thousands of rupees worth ammunition components are used up, in addition to technical facilities at proof ranges. This severely restricts the number of variables that can be followed up during development and the times they can be tried for repeatability. The closed vessel is ideal for this work. Its requirement of propellant is only a few pounds and no auxiliary components are needed. With a closed vessel equipment installed in the Factory a number of firings can be carried out in day and thus any number of variables can be tried out as fast as the factory can make them. In some trials recently, by using closed vessel technique, a very unorthodox method of Ultra Rapid Drying of Solvent Type Propellants in a single day was proved feasible. The whole work took about a week. The results are given in Oscillograms in Fig. X. Incidentally this process has made closed vessel checks available, right at the cordite press. The vivacity figures for a day's propellant production would be available next day, if samples are processed by this Ultra Rapid Drying method. Much more important applications to quick production of propellant in emergencies, are also indicated by this process. This should be of particular interest to the authorities planning propellant production.

Chemical Kinetics of Running Propellant

C.V. Comparison of the burning characteristics of similar prepellants with limited variants in composition, has helped in some new fundamental understanding of the burning rate phenomena. Some oscillograms relating to these are given in Fig. XI. It is observed, that coolants soluble in NC-NG-gel, like carbamite and organic Esters, reduce the burning rate considerably. Sparingly soluble coolants, like Mineral Jelly, affect it less. Inert solids, like cryolite and inorganic sulphates, have little effect on the burning rate, but cool the final gases and react with them, where possible. These data are of fundamental importance

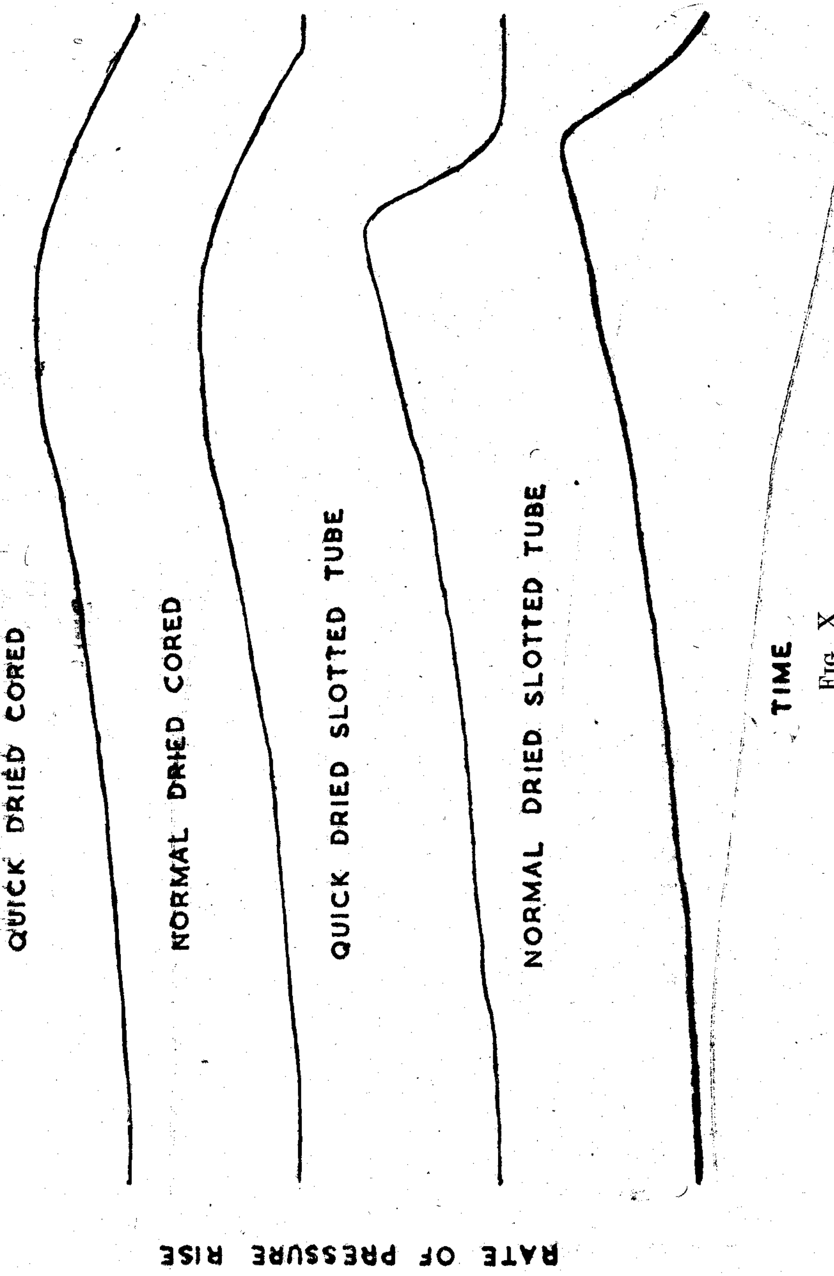


FIG. X
RAPID DRYING OF SOLVENT CORDITES

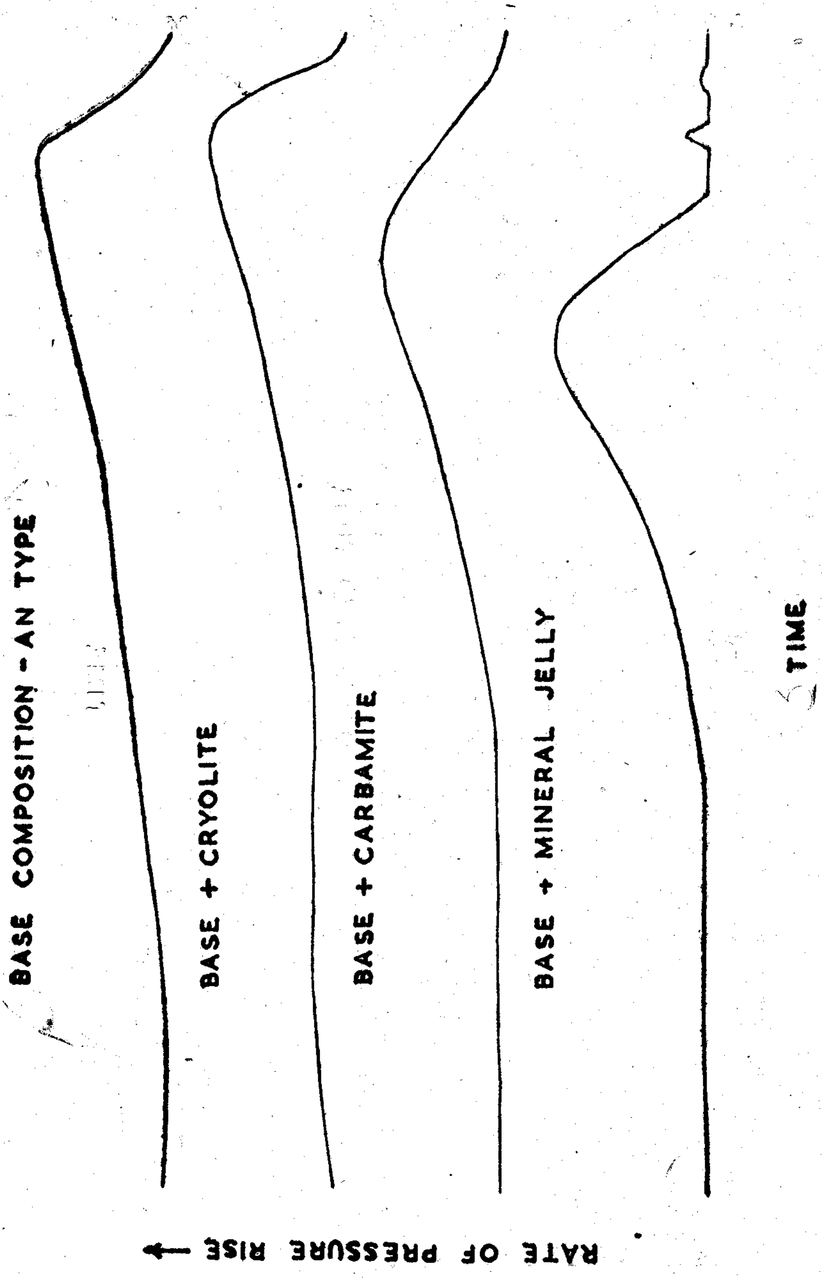


FIG. XI
EFFECT OF COOLANTS ON BURNING RATE

in designing 'tailor-made' propellants. As an instance, it is a common requirements for a propellant today that it should (1) give as cool gases as possible to reduce gun flash and gun erosion (2) as good an ignitability as hot propellants at even subzero temperatures and (3) have as stable a burning rate as possible even at lower pressures. To the propellant designer today, these are contradictory material requirements. But they are feasible, if we knew more about burning rate phenomena.

Indigenous Cool Flashless Propellant Based on New Principles

Based on some of the above fundamental data an indigenous propellant has been designed. It works on a new principle of *hot flame, but cool gases.* It has a base composition of nitrocellulose and nitroglycerine as in all hot double base propellants. It has therefore a hot flame and is thus expected to have all its advantages (*e.g.*) good ignition at low temperatures and stability of burning at medium pressures. Its gases get cool by dilution with inert vapours, produced from evaporation of an inert solid additive (cryolite) in the propellant. Thus, the propellant has all the advantages of cool propellant (*viz.,*) flashlessness and low gun erosion. This propellant awaits final gun trials. It features a new dimension in propellants viz., *after burning characteristics.*—In addition to the features commonly controlled in propellants, the size, shape and composition of the solid additives can be designed to influence this new *after burning characteristic* of the propellant. This propellant with most of the advantages of both the hot and cool propellants, is of immediate importance, as indigenous picrite is not available for manufacture of cool propellants in India. This should interest the authorities planning future propellant production in the country.

Discussion

Dr. Kartar Singh and Major Umapathiswaran took part in the discussion. The former wanted to know the effect of ageing on solventless cordite. The speaker replied that there was possibility of some strains inside such propellants and he mentioned about the difference in rates of burning of a propellant in the longitudinal and transverse directions. Dr. Kartar Singh said that in this connection it was for consideration whether such behaviour was due to strains in the propellant or due to orientation of molecules. Major Umapathiswaran wanted to know the difference between the results obtained from closed vessel data and actual gun firing. Shri B.B. Chaudhuri Supdt. TDE (Military Explosives) replied that they tallied fairly closely but more data has to be obtained on results of Closed Vessel and actual gun firings. Shri Chaudhuri emphasised the importance of Closed Vessel technique in the assessment of internal ballistics in development and indigenous manufacture of propellants. In this connection he mentioned a number of propellants both small arms ammunition and gun ammunition in the development of which Closed Vessel Technique had proved extremely useful.

Shri Sivaramakrishnan in presenting his paper explained with the help of slides the different types of pressure-time curves obtained on closed vessel with cord, tubular and multi-tubular propellants. He explained the usefulness of closed vessel data on determining propellant charge weight, burning characteristics of new composition and how the latter has helped them in formulation of a propellant composition for Naval 4-in Mk 16* gun. He stressed upon the necessity for making increasing use of the Closed Vessel technique in study of propellants not only for experimental work but also for control of production.

CONCLUDING REMARKS BY THE CHAIRMAN

As the allotted time had expired, the Chairman declared the Seminar closed and expressed his appreciation of the valuable contribution made by the speakers to our knowledge of explosives and their properties. Dr. Kothari thanked the Chairman for conducting the Seminar and in his concluding remarks brought out the necessity for expansion of laboratories for research and development work on explosives.