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## A small scale study of the fragmentation effect of aluminised RDX/binder compositions [R]

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L. Cottle



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MINISTRY OF DEFENCE

ROYAL ARMAMENT RESEARCH AND DEVELOPMENT ESTABLISHMENT

R.A.R.D.E. MEMORANDUM 15/70

AD-399780

# A small scale study of the fragmentation effect of aluminised RDX/binder compositions

P. Emmott, B.Sc., Ph.D., A.R.I.C. (E1)
L. Cottle, (E1)

Summary

The shattering effect of charges of various aluminised RDX/polyurethane and other high explosive compositions has been evaluated in terms of a fragmentation parameter derived from the mass distribution of the fragments of the metal casings used to contain the charges. The effect of variations in the proportions of the explosive components has been investigated and the data used to estimate the fragmentation effect of practical compositions. The relationship between the fragmentation and other explosive properties of these compositions has been studied.

Approved for issue:

D. F. Runnicles, Principal Superintendent, 'E' Division



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## CONTENTS

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## 1. INTRODUCTION

The standard R.A.R.D.E. calorimetric method[1] for the determination of the heat of explosion of explosives has been extended to include the determination of fragmentation parameters[2] based on the mass distribution of the fragments from the standard mild steel cylindrical container used for the explosive charge. The latter is detonated in a special evacuated closed vessel of known thermal capacity. The temperature rise is measured and certain corrections are applied to the measured heat change based on the analysis of the explosion products. The analysis of the solid products necessitates the collection of all materials left in the calorimeter including the fragments of the steel casing from which any solid deposits are separated. These steel fragments are used to evaluate the fragmentation parameters of the explosive.

It was decided to apply this technique to the study of the fragmentation effect of aluminised RDX/Binder compositions. A number of experimental compositions containing polyurethane as the binder had already been prepared and used for heat of explosion determinations[3] and the casing fragments had been retained. Since these compositions had a systematically varied polyurethane and aluminium content it was proposed to use them to obtain information about the effect of these compositional variables on fragmentation and to attempt to relate this with other explosive properties, such as velocity of detonation, heat of explosion and volume of gaseous explosion products. It was hoped that the data obtained from this series of experimental compositions could be used to predict the fragmentation effect of RDX/binder/aluminium charges in general. To investigate this possibility other RDX-based explosives of current interest were also studied.

## 2. THE NUMBER-MASS DISTRIBUTION LAW

The fragment size distribution can be expressed in terms of the number of fragments in a given mass range by the basic frequency law :-

$$dN = f(m)dm$$

where the integral of dN represents the number of fragments each with a mass lying between two standard mass intervals $m_1$ and $m_2$. The search for the functional form f(m) of this law led to an empirical equation derived by Mott[4] which can be expressed essentially as

$$N_m = N_o \, e^{-Am^{\frac{1}{2}}}$$

where $N_m$ is the number of fragments each with a mass lying between the mass intervals $m_1 = m$ and $m_2 =$ infinity. $N_o$ is the total number of fragments, and, like A, is a constant for a given explosive and casing. The constant A will be referred to as the number-mass parameter. It can be seen that a plot of log $N_m$ against $m^{\frac{1}{2}}$ should enable A and $N_o$ to be determined. The difficulty of extrapolating such a curve from m = 2g (the lowest mass considered in practice) to m = 0 on a logarithmic scale makes any evaluation of $N_o$ unreliable. It has been found convenient in this work to express values of the parameter A for RDX/binder/aluminium compositions as a percentage, relative to A = 100 for pure RDX of the same density. This relative percentage value will be referred to as the fragmentation effect of the composition. Any absolute value of A is difficult to interpret in view of the non-ideal nature of the steel container and also of the secondary fragmentation due to primary fragments striking the closed vessel walls.

Two other fragmentation parameters have been considered in earlier work[2]; the weight-mass parameter, and the ratio parameter. Neither revealed any information about fragmentation not offered by the number-mass parameter and since the latter offers the optimum combination of ease of calculation together with precision of results, it was chosen in the present work to express the experimental data.

It should be noted that the higher the value of the parameter A, the greater is the shattering effect or disruptive performance of the explosive and the smaller are the resulting fragments of the steel casing. The parameter A is thought to be associated with the detonation pressure of an explosive rather than the heat of explosion.

## 3. EXPERIMENTAL

The procedure and apparatus described in this Memorandum were identical to those used in the R.A.R.D.E. calorimetric method for the determination of heats of explosion[1] except that the washed fragments were retained for mass distribution studies. The term 'heat of explosion' is used here to denote the energy release, measured under the conditions of the experiment, when the explosive charge is detonated. Whilst complete detonation is achieved in these experiments it is considered advisable to reserve the term 'heat of detonation' for the theoretical energy release at the instant of detonation; this heat is modified in practice by the rapid shifts of equilibrium which occur just after detonation. Essentially the procedure consisted of detonating 100g of the explosive in a standard cylindrical casing which was contained in a 10 litre evacuated closed vessel from which the fragments were collected after detonation.

The charges used in this work were all of density 1.63 g/cc and were made up from one inch diameter pellets of explosive. A number of the charges were prepared from experimental RDX/polyurethane/aluminium compositions in which the polyurethane and aluminium content were systematically varied. The other charges were of explosives of current interest, i.e. RDX/wax (91/9 and 88/12), plastic explosive PE4 (88/12), RDX/silicone (88/12), RDX/polyurethane (88/12), Hexal (82/18 RDX/aluminium with 2% graphite), RDX/wax/aluminium (71/9/20 and 73/12/15), PE6/Al (an aluminised version of PE4 containing 15% aluminium and 11% binder) and RDX/polyurethane/aluminium (70/13/17).

The cylindrical casings[1] were made from mild steel BS/STA5/V3 and weighed about one kg. They were 9.7 in long, with $\frac{1}{4}$ in thick walls and an internal diameter of one inch. The casing was threaded at either end to receive two end caps, one of which was drilled so as to allow the insertion of an electric detonator.

After detonation the fragments were collected and washed. The two end caps, usually intact, were discarded together with the metal plugs used to fill any space between the charge and the bottom cap. It was also found that more consistent results were obtained if any fragments which included the threaded ends of the casing were also disregarded. These fragments, usually large and readily identifiable, were part of the casing supported by the end caps and not in direct contact with the explosive charge.

The individual fragments were weighed to the nearest 0.1g on a direct reading balance, the larger fragments being chosen visually and weighed first. This weighing process was carried out until all fragments weighing more than or equal to 2g had been weighed. This necessitated weighing many fragments less than 2g in weight to ensure that no fragment weighing 2g or over was overlooked. Fragments weighing less than 2g were bulked together.

## 4. EVALUATION OF THE NUMBER-MASS PARAMETER

An example of the tabulation and calculation of the mass distribution results is given in Table 1 for a 100g charge of RDX (density = 1.63 g/cc). The weight of all fragments of more than 14g are grouped together as are those weighing less than 2g. The remaining fragments are grouped in mass intervals of 2g, i.e. the number of individual fragments in the mass ranges 14g to 12g, 12g to 10g, etc are given.

The results given in Table 1 exemplify the method of calculation of the number-mass parameter A. The cumulative total number (N) of fragments having a mass greater than or equal to m (where m = 14g, 12g etc down to 2g) is first found and log N plotted against $m^{\frac{1}{2}}$ (Fig.1). The slope of the straight line so obtained gives the value of A, and for the example quoted i.e. RDX of density 1.63 this value was 0.79. In a similar manner the parameter A was determined for the different RDX/binder/Al compositions and the parameter A expressed as a percentage, relative to RDX = 100 at the same density.

The reproducibility of the determination of the parameter A has been determined[2] for TNT, the coefficient of variation being about 6%. Where replicate results are available for the charges considered here, the reproducibility is slightly worse than this e.g. the results for RDX/10% PU would indicate a coefficient of variation of about 8%. This might indicate some difficulty in preparing pellets of reproducible and homogeneous composition.

## 5. THE EFFECT OF VARIATIONS OF POLYURETHANE AND ALUMINIUM CONTENT ON FRAGMENTATION

The effects of variations of polyurethane content on fragmentation are shown by the curves in Fig.2 which are based on the results given in Table 2. It can be seen that the fragmentation is decreased by increasing the polyurethane content and the effect is usually greater than would be expected on a straight dilution basis e.g. 10% polyurethane decreased the fragmentation of RDX by 15%.

The effect of variations of aluminium content on fragmentation are shown by the curves in Fig.3 which are based on the results given in Table 3. In general, increasing the aluminium content results in a decrease in the fragmentation but the effect is usually less than would be expected from the amount of aluminium present.

The curves shown in Fig.2 and Fig.3 can be combined in the form of a triangular co-ordinate graph (Fig.4) which shows lines of constant fragmentation effect.

## 6. THE ESTIMATION OF THE FRAGMENTATION EFFECT OF NEW COMPOSITIONS

The triangular co-ordinate graph (Fig.4) can be used for estimating the fragmentation of compositions containing up to 20% binder and up to 35% aluminium by interpolation between the lines of constant fragmentation effect. Table 3 compares the experimental fragmentations with the fragmentations estimated using Fig.4 and includes data for the experimental series of RDX/polyurethane/aluminium compositions and the other compositions. It can be seen that the value obtained using Fig.4 is quite close to the experimental result, the average error involved being about 4%. The validity of using this graph for RDX/binder/aluminium compositions in general is confirmed by the relevant results for the other compositions. With the possible exception of the silicone composition the use of different inert binders does not significantly affect the fragmentation properties of the explosives.

It should be noted that the fragmentation as described by the parameter A is a small scale measure of performance, determined under standardised conditions and best expressed as a relative value. It would be difficult to apply the results to the prediction of the fragmentation of actual explosive stores without taking into account the scaling laws[5] which need to be applied to such variables as the weight of explosive, the ratio of weight of explosive to the weight of the whole store, the geometry of the store and the thickness of the casing. It is hoped to investigate the applicability of such scale laws in the future.

## 7. THE RELATIONSHIP BETWEEN FRAGMENTATION AND OTHER EXPLOSIVE PROPERTIES

### 7.1 Detonation pressure

The correlation of fragmentation with the theoretically calculated detonation pressure of pure explosives has already been noted[2]. This relationship would be difficult to apply to aluminised RDX/binder compositions because of the problem of calculating the detonation pressure of these explosive mixtures, though there is no reason to suppose the same correlation would not hold good.

The Plate Dent test[6] has been used as a small scale measure of explosive performance and is considered to give a good indication of the detonation pressure of explosives. In this test the volume of the dent produced in the surface of a steel plate by an 8g pellet of the explosive is related to the volume produced by an 8g pellet of a standard explosive fired on the same plate. The Plate Dent test results for the experimental and the supplementary compositions are given in Tables 4 and 5 respectively, and are expressed relative to RDX = 100, all pellets being of density 1.63 g/cc. In spite of the lack of confinement of the pellets and other experimental differences the agreement between the Plate Dent test and the fragmentation effect is satisfactory.

7.2 Velocity of detonation

A direct relationship between fragmentation and the square of the velocity of detonation (D) should hold good in the case of pure explosives because the detonation pressure was calculated[2] from the product 'density x $D^2$', and the density of the different charges did not vary to any great extent. In the case of the RDX/binder/Al charges there are few results available for the compositions and densities involved. The relevant data, obtained from recent and wartime R.A.R.D.E. sources, are shown in Tables 4 and 5 (at charge density 1.63 g/cc). It would appear that whilst an increase in the velocity of detonation is always accompanied by an increase in fragmentation, fragmentation values for RDX/binder compositions appear to be lower than would be indicated by the $D^2$ values, and the fragmentation values for RDX/aluminium compositions appear to be higher than would be expected. It is possible that the enhanced energy of the aluminised system might play some part in improving the fragmentation.

It can be seen from Table 5 that the RDX/silicone composition has a low velocity of detonation result when compared with the other 88/12 compositions. This is reflected in its low fragmentation and plate dent test result and it is proposed to investigate this effect further.

Work is proceeding on the theoretical prediction of the velocity of detonation of aluminised explosive/binder systems and despite the difficulties of preparing suitable samples it is hoped to accumulate more experimental velocity of detonation data for comparative purposes.

7.3 Heat of explosion

The term 'heat of explosion' as used here refers to the experimental value determined[4] at R.A.R.D.E. and not to any value calculated from theories of detonation. The data given in Table 4 enable the heat of explosion ($H_e$) to be compared graphically with fragmentation (Fig.5) the trends being confirmed by the supplementary results in Table 5. In the case of charges containing no aluminium or the same amount of aluminium there seems to be a direct relationship between $H_e$ and fragmentation; both decrease with increase in polyurethane content. The effect of aluminium in amounts greater than 10% is to cause the fragmentation to decrease as the $H_e$ increases.

7.4 Volume of gaseous explosion products

A graphical comparison of the gas volume[3] with fragmentation (Fig.6) can be made using the data given in Table 4 and the trends confirmed by the supplementary results in Table 5. A decrease in the volume of the gaseous products is always accompanied by a decrease in the fragmentation. The volume of the explosion products might reasonably be expected to have this effect and, together with the rate of release of energy, (i.e. the velocity of detonation), and the amount of energy released, should make up the more fundamental factors which affect the disruptive performance of an explosive.

## 8. CONCLUSIONS

The determination of the fragmentation parameter of explosives as an extension of the method used to measure heat of explosion has been applied to aluminised RDX/binder compositions. Whilst compositions based on a polyurethane binder have been mainly considered, work on other compositions indicates that the type of binder used has little effect on fragmentation.

The effect of different amounts of binder and aluminium on the fragmentation has been investigated; the results indicate that both have an adverse effect.

Fragmentation has been compared with other explosive parameters and is considered to be associated with detonation pressure, though other factors such as heat of explosion and volume of gaseous explosive products are also relevant.

The results have been used to construct a triangular co-ordinate graph which can be used to estimate the fragmentation effect of practicable aluminised RDX/binder compositions.

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3. P. Emmott and L. Cottle, R.A.R.D.E. Memo 27/68
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## 10. TABLES OF RESULTS

TABLE 1

| An example of the fragmentation mass distribution results 100g charge of RDX of density 1.63 g/cc | | | | | |
|---|---|---|---|---|---|
| Mass range g | Numbers of fragments | Lower mass limit "m" g | Total number of fragments "N" | Log N | $m^{\frac{1}{2}}$ |
| over 14 | 2 | 14 | 2 | 0.30 | 3.73 |
| 14-12 | 1 | 12 | 3 | 0.48 | 3.46 |
| 12-10 | 2 | 10 | 5 | 0.70 | 3.16 |
| 10-8 | 5 | 8 | 10 | 1.00 | 2.83 |
| 8-6 | 7 | 6 | 17 | 1.23 | 2.45 |
| 6-4 | 28 | 4 | 45 | 1.65 | 2.00 |
| 4-2 | 54 | 2 | 99 | 2.00 | 1.41 |
| 2-0 | | | | | |
| plot of $m^{\frac{1}{2}}$ against log N gives a straight line having a slope = 0.79 = A | | | | | |

TABLE 2

| Fragmentation effect of experiemental RDX composition of varying PU and Al content | | | | |
|---|---|---|---|---|
| Composition | | | Number-mass parameter A | Fragmentation (RDX = 100) % |
| RDX % | PU % | Al% | | |
| 100 | | | 0.79 | 100 |
| 95 | 5 | | 0.71, 0.74 | 92 |
| 90 | 10 | | 0.61, 0.74, 0.64, 0.69 | 85 |
| 87 | 13 | | 0.62 | 78 |
| 85 | 15 | | 0.63, 0.60 | 78 |
| 85.5 | 4.5 | 10 | 0.73 | 92 |
| 76 | 4.0 | 20 | 0.64 | 81 |
| 66.5 | 3.5 | 30 | 0.53 | 67 |
| 81 | 9 | 10 | 0.62 | 79 |
| 72 | 8 | 20 | 0.52 | 66 |
| 63 | 7 | 30 | 0.45 | 57 |
| 76.5 | 13.5 | 10 | 0.54 | 68 |
| 68 | 12 | 20 | 0.42 | 53 |
| 59.5 | 10.5 | 30 | 0.28 | 35 |
| 90 | | 10 | 0.78, 0.79 | 99 |
| 80 | | 20 | 0.63, 0.74 | 87 |
| 70 | | 30 | 0.58, 0.53 | 70 |

TABLE 3

| Comparison of actual fragmentation with predicted value | | | | | |
|---|---|---|---|---|---|
| Composition | | | Measured fragmentation (RDX = 100) | Estimated fragmentation using Graph 4 | Error % |
| RDX % | Binder % | Al % | | | |
| 100 | 0 | 0 | 100 | 100 | 0 |
| 95 | 5 (PU) | 0 | 92 | 94 | 2 |
| 90 | 10 (PU) | 0 | 85 | 86 | 1 |
| 87 | 13 (PU) | 0 | 78 | 80 | 2 |
| 85 | 15 (PU) | 0 | 78 | 76 | 2 |
| 85.5 | 4.5 (PU) | 10 | 92 | 91 | 1 |
| 76 | 4.0 (PU) | 20 | 81 | 81 | 0 |
| 66.5 | 3.5 (PU) | 30 | 67 | 66 | 1 |
| 81 | 9 (PU) | 10 | 79 | 80 | 1 |
| 72 | 8 (PU) | 20 | 66 | 68 | 3 |
| 63 | 7 (PU) | 30 | 57 | 55 | 3 |
| 76.5 | 13.5 (PU) | 10 | 68 | 66 | 3 |
| 68 | 12 (PU) | 20 | 53 | 54 | 2 |
| 59.5 | 10.5 (PU) | 30 | 35 | - | - |
| 90 | 0 | 10 | 99 | 99 | 0 |
| 80 | 0 | 20 | 87 | 90 | 3 |
| 70 | 0 | 30 | 70 | 73 | 4 |
| 91 | 9 (Wax) | 0 | 87 | 88 | 1 |
| 88 | 12 (Wax) | 0 | 80 | 83 | 4 |
| 88 | 12 (PE4) | 0 | 89 | 83 | 7 |
| 88 | 12 (Silicone) | 0 | 76 | 83 | 9 |
| 88 | 12 (PU) | 0 | 82 | 83 | 1 |
| 82 | Hexal | 18 | 87 | 89 | 2 |
| 71 | 9 (Wax) | 20 | 67 | 66 | 1 |
| 73 | 12 (Wax) | 15 | 67 | 64 | 4 |
| 74 | 11 (PE6) | 15 | 70 | 67 | 4 |
| 70 | 13 (PU) | 17 | 53 | 56 | 6 |

TABLE 4

Comparison of fragmentation with other explosive properties of experimental RDX/PU/Al compositions

| Composition RDX % | PU % | Al % | Fragmentation (RDX = 100) | Heat of explosion cals/g | Volume of gas ml/g | Plate dent RDX = 100 | Velocity of detonation km/sec |
|---|---|---|---|---|---|---|---|
| 100 | 0 | 0 | 100 | 1345 | 858 | 100 | 8.4 |
| 95 | 5 | 0 | 92 | 1280 | 860 | 98 | 8.3 |
| 90 | 10 | 0 | 85 | 1190 | 866 | 90 | 8.3 |
| 87 | 13 | 0 | 78 | 1159 | 860 | | 8.0 |
| 85 | 15 | 0 | 78 | 1130 | 860 | 68 | 8.0 |
| 85.5 | 4.5 | 10 | 92 | 1473 | 830 | | |
| 76 | 4.0 | 20 | 81 | 1645 | 746 | | |
| 66.5 | 3.5 | 30 | 67 | 1842 | 580 | | |
| 81 | 9 | 10 | 79 | 1386 | 835 | | |
| 72 | 8 | 20 | 66 | 1628 | 742 | | |
| 63 | 7 | 30 | 57 | 1867 | 559 | | |
| 76.5 | 13.5 | 10 | 68 | 1288 | 848 | | |
| 68 | 12 | 20 | 53 | 1552 | 749 | | |
| 59.5 | 10.5 | 30 | 35 | 1732 | 580 | | |
| 90 | 0 | 10 | 99 | 1550 | 837 | 93 | 7.8 |
| 80 | 0 | 20 | 87 | 1750 | 746 | 83 | 7.2 |
| 70 | 0 | 30 | 70 | 1950 | 574 | 67 | 6.6 |

TABLE 5

Comparison of fragmentation with other explosive properties of the other compositions

| Composition RDX % | Composition binder % | Composition Al % | Fragmentation (RDX = 100) | Heat of explosion cals/g | Volume of gas ml/g | Plate dent RDX = 100 | Velocity of detonation km/sec |
|---|---|---|---|---|---|---|---|
| 91 | 9 (Wax) | 0 | 87 | 1223 | 823 | 90 | 8.3 |
| 88 | 12 (Wax) | 0 | 80 | 1177 | 826 | 79 | 8.3 |
| 88 | 12 (PE4) | 0 | 90 | 1195 | 872 | 83 | 8.3 |
| 88 | 12 (Silicone) | 0 | 76 | 1243 | 823 | 72 | 7.8 |
| 88 | 12 (PU) | 0 | 82 | 1184 | 826 | 80 | 8.2 |
| 82 | Hexal | 18 | 87 | 1715 | 742 | 75 | 7.3 |
| 71 | 9 (Wax) | 20 | 67 | 1660 | 762 | 49 | 7.2 |
| 73 | 12 (Wax) | 15 | 67 | 1518 | 802 | 50 | 7.6 |
| 74 | 11 (PE6) | 15 | 70 | 1511 | 823 | 67 | 7.6 |
| 70 | 13 (PU) | 17 | 53 | 1430 | 780 | 50 | 7.5 |

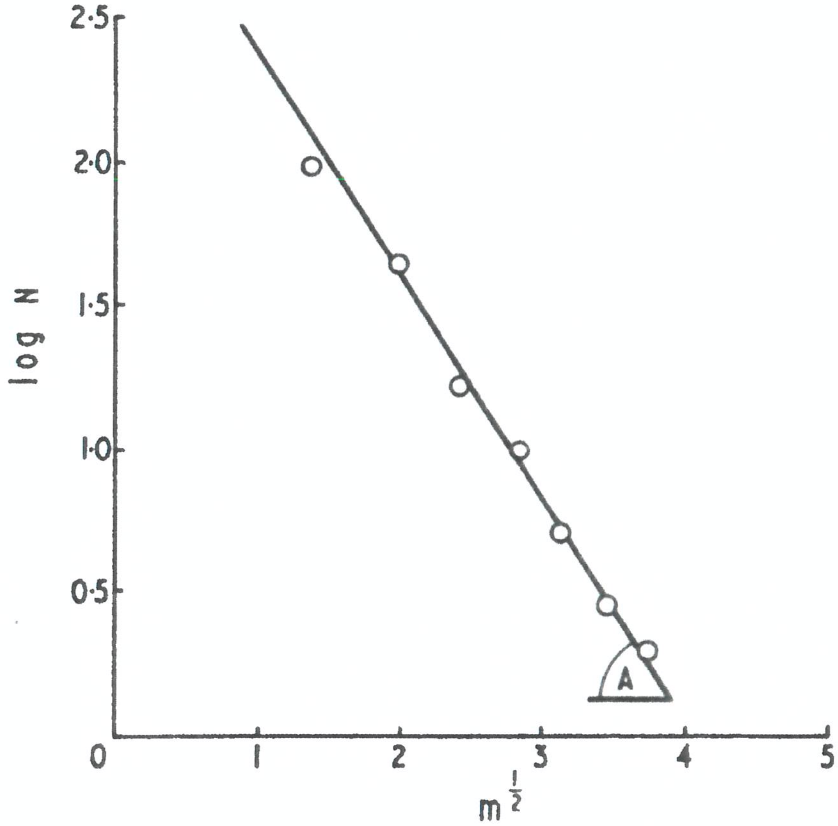


FIG. I NUMBER — MASS PARAMETER "A"
(100 g RDX CHARGE)

FIG. 2

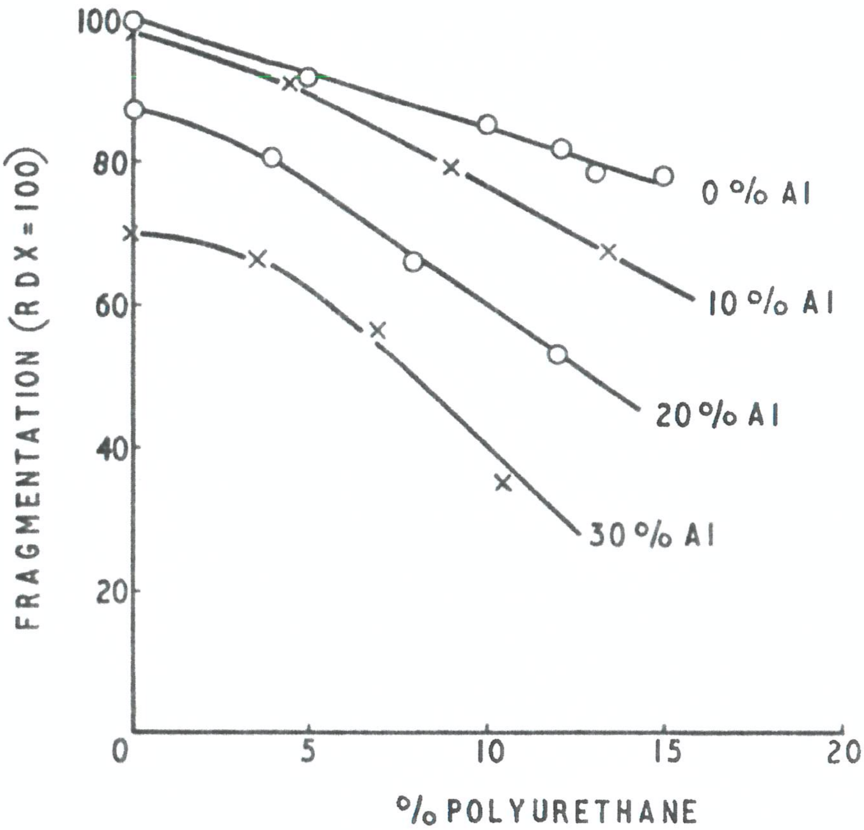


FIG. 2 THE EFFECT OF VARIATIONS OF POLYURETHANE CONTENT ON FRAGMENTATION

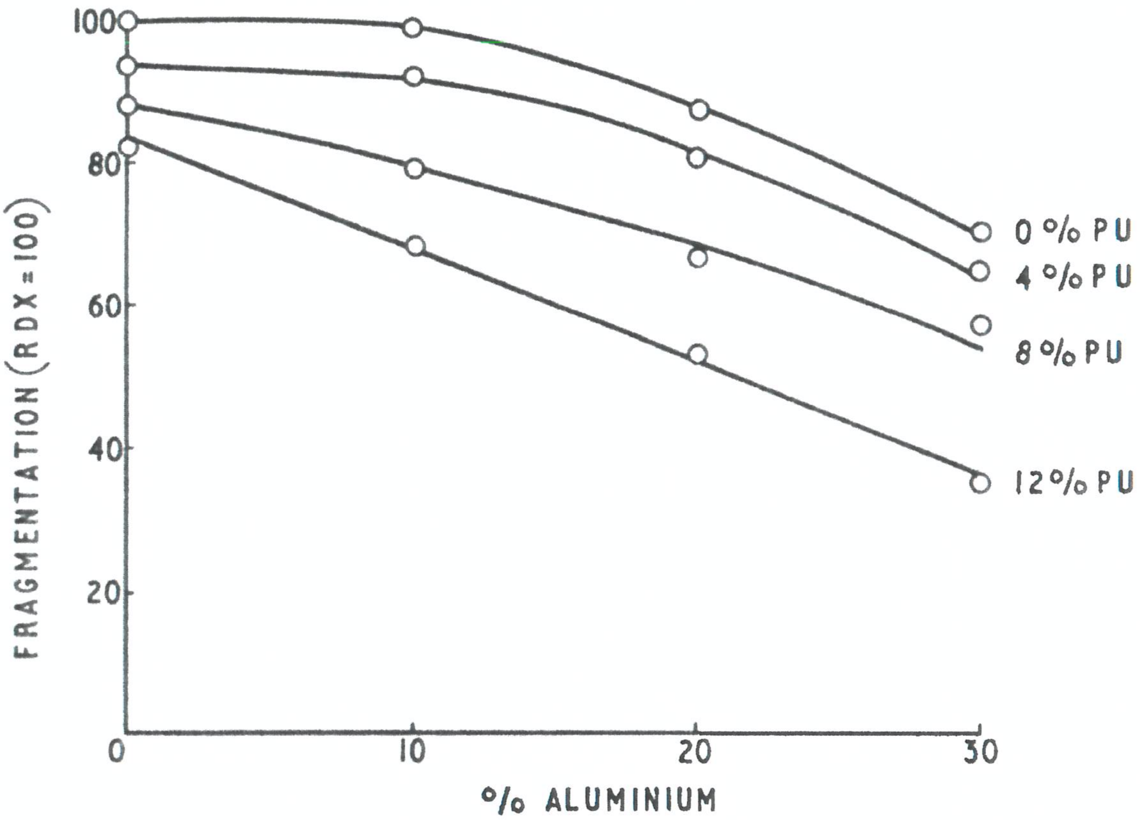


FIG. 3 THE EFFECT OF VARIATIONS OF ALUMINIUM CONTENT ON FRAGMENTATION

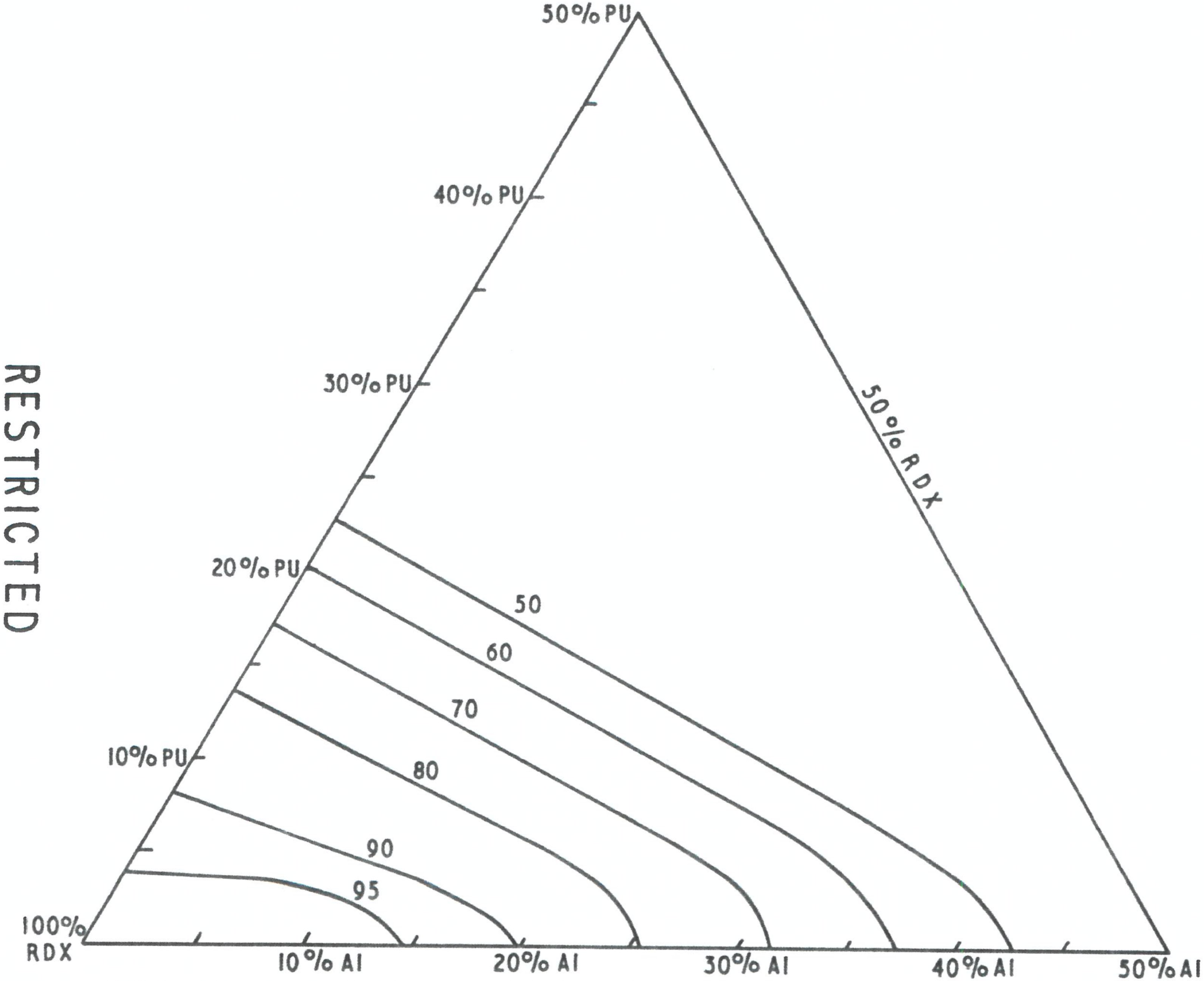


FIG. 4 LINES OF CONSTANT FRAGMENTATION EFFECT (RDX=100)



FIG.4

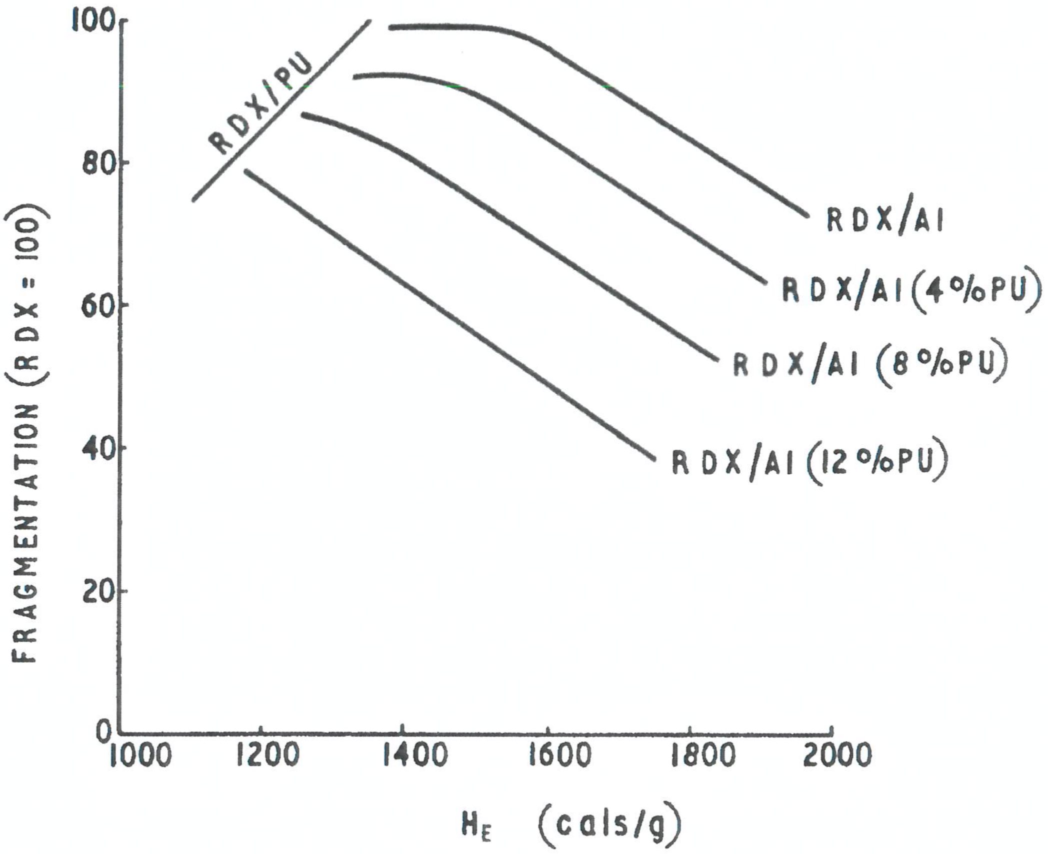


FIG. 5 HEAT OF EXPLOSION AND FRAGMENTATION

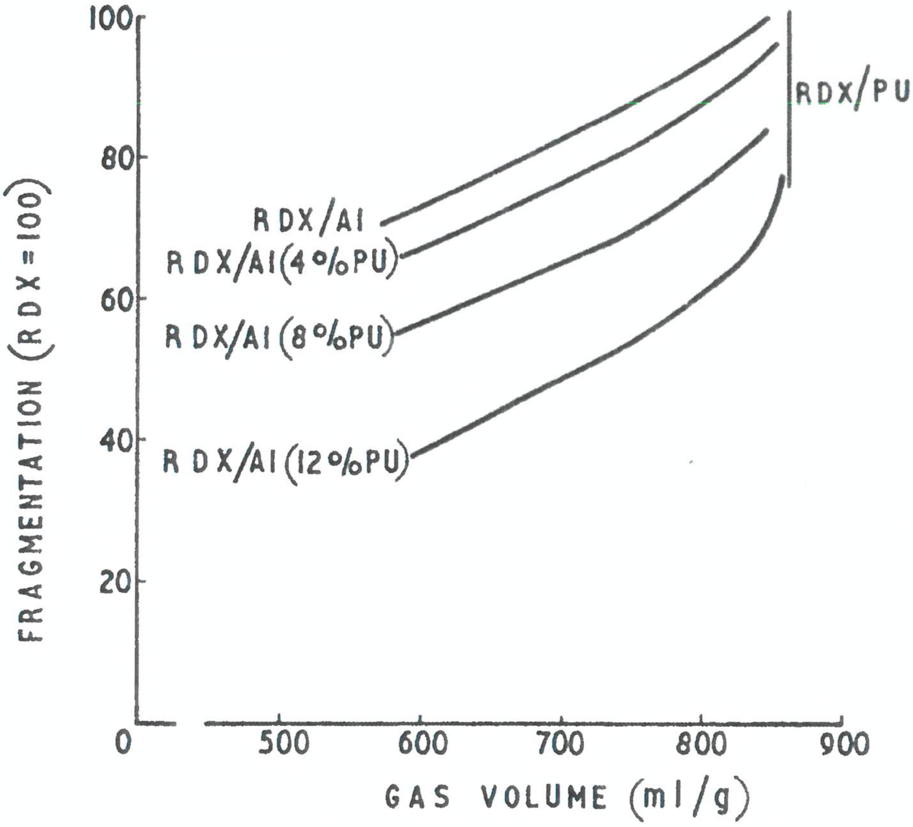


FIG. 6 VOLUME OF GAS PRODUCED AND FRAGMENTATION

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P. Emmott, L. Cottle — April 1970

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