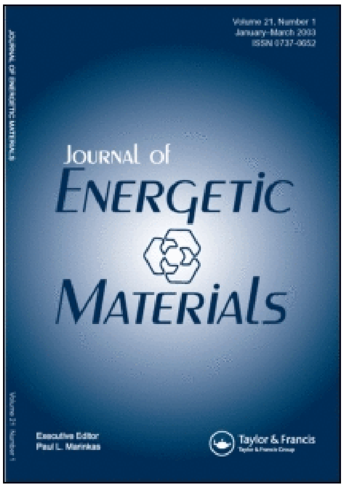

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COMBUSTION AND THERMAL BEHAVIOUR OF BALLISTICALLY MODIFIED EVA AND ESTANE BASED RDX-AP PROPELLANTS

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ABSTRACT

This paper reports the findings of the combustion and thermal studies on RDX-AP based propellants with ethylene vinyl acetate (EVA) and polyurethane-ester-MDI (Estane) binder systems plasticised with triacetin (TA) and glycidyl azide pre-polymer (GAP). Effect of incorporation of selected ballistic modifiers namely iron oxide, copper chromite, basic lead salicylate + cuprous oxide + carbon black combination and sodium borohydride (adsorbed on aluminium oxide) was also studied during this work. Incorporation of GAP as plasticizer in place of TA led to improvement in F by 36-52 J/g. Closed vessel evaluation results were in close agreement with the theoretically predicted performance. Burn rate enhancement by ballistic modifiers was observed in both acoustic burn rate experiments as well as closed vessel test. A major finding was the realization of pressure index value of the order of 0.65 – 0.68 with copper chromite in the high pressure regions (14 – 200 MPa) which is not reported earlier. DTA and DSC studies indicate that RDX decomposition is the major process during propellant degradation and ballistic modifiers catalyse condensed-phase/near-surface reactions involving GAP.

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INTRODUCTION :

Thermoplastic elastomers (TPEs) are basically non-homogeneous polymeric systems in which an elastomeric unit has been polymerized with a thermoplastic unit to produce a co-polymer having a central block of elastomer terminated with thermoplastic blocks. The end result of this molecular construction is a material which has the properties of vulcanised rubber and can be processed in a manner similar to thermoplastics[1]. Basically, TPEs offer the advantages of desired cohesive strength upto moderately high temperature and flexibility even at sub-zero temperatures. The system may be remelted and reprocessed a number of times providing consequent advantages to the formulator like simplified processing and lower production losses[2]. Owing to these typical characteristics, TPEs have potential of use as binder for rocket/gun propellants and explosives[3-6]. Moreover, major advantage of TPEs over chemically cured and crosslinked hydroxy/carboxy terminated polybutadiene binders in current use is the ease in demilitarizing of filled munitions[6].

During present work, RDX-AP based formulations with TA/GAP plasticized EVA and Estane binder systems were subjected to combustion studies. Effect of inclusion of selected ballistic modifiers was also evaluated. DTA & DSC data on all the systems was generated in the course of this study. An attempt has been made to propose prevailing mechanism for combustion pattern observed on the basis of the thermal and ballistic data generated during this work as well as findings of other researchers.

EXPERIMENTAL :

Propellant formulations evaluated in this study comprised 70 - 60% RDX (~ 5μ), 10-20% AP (~10 μ), 16% TPE binder (EVA/Estane) and 4% plasticizer (TA/GAP). In ballistically modified compositions, iron oxide/copper chromite/basic lead salicylate + cuprous oxide + carbon black combination and sodium borohydride (adsorbed on aluminium oxide) were incorporated at the level of 2 parts (by weight) over and above 100 parts (by weight) of formulation. Solvent technique was adopted to process the formulations[7]. TPEs were solvated by mixing with plasticizer and required quantity of solvent (toluene/acetone) in a sigma blade mixer. RDX was added in installments to the solvated binder matrix. The contents were incorporated for two hours. Subsequently, the mix was dried at 40°C to remove the solvent. Dried crumbs were hot rolled at 60-80°C to obtain extrudable propellant sheets. Computer software (Therm) developed by HEMRL was used to theoretically compute thermochemical parameters[8]. The propellant samples in ribbon form were subjected to combustion in a 100 cc closed bomb at 0.2 g/cc loading density to determine the delivered impetus. Data obtained on closed vessel (CV) firing was acquired using piezoelectric gauge in conjunction with indigenously developed data acquisition system. All the experiments were performed on propellants conditioned at 30 ± 2°C. Strand burn rates were determined in the pressure range of 3.4 - 10.8 MPa by combusting strand (6 x 6 x 100 mm) in the nitrogen pressurized steel bomb. Acoustic signals generated by the deflagrating sample were unidirectionally transmitted through the water medium and sensed by the piezo-electric transducer of resonance frequency of 200 kHz. Thermal studies were carried out at a heating rate of

10°C/min on indigenously fabricated Differential Thermal Analyser (DTA) in air and Differential Scanning Calorimeter (DSC) of Perkin Elmer Make in N_2 atmosphere.

Results & Discussion :

BALLISTICS :

Closed Vessel Combustion

The theoretical computation of ballistic parameters revealed that the propellants with 70% RDX and 10% AP combination based on TA plasticised EVA binder give F of the order of 1128 J/g with T_f 2763 K and those based on Estane binder give F of the order of 1086 J/g with T_f 2716 K. On increase in AP content to 20% (at the cost of RDX) F increased to the extent of 1136 and 1103 and T_f to 2869 – 2824 respectively. GAP plasticised formulations exhibited higher F (by 36 – 52 J/g) and T_f (by 115-119 K) than corresponding TA plasticized formulations. CV firing experiments gave F values in close agreement with the theoretically computed data (Table 1). The pressure burn-rate relationships obtained for various systems are summarized below and depicted in Fig.1-4.

$r = 0.113\ P^{1.06}$	$r = 0.155\ P^{0.95}$	$r = 0.133\ P^{0.91}$	$r = 0.162\ P^{0.90}$
70% RDX 10% AP	***60% RDX 20% AP***	***70% RDX 10% AP***	***60% RDX 20% AP***
TA		**GAP**	

EVA Based Formulations

$r = 0.092\ P^{0.98}$	$r = 0.126\ P^{0.90}$	$r = 0.105\ P^{0.95}$	$r = 0.137\ P^{0.90}$
70 % RDX 10% AP	***60% RDX 20% AP***	***70% RDX 10% AP***	***60% RDX 20% AP***
TA		**GAP**	

Estane Based Formulations

As the results obtained for composition based on 60% RDX and 20% AP in EVA binder system were superior to those for other compositions studied, in terms of relatively higher burning rate and lower pressure index, it was selected for ballistic modification. The pressure-burn rate relationships of the ballistically modified systems obtained are given below (Fig.5 & 6) :

$r = 0.183\ P^{0.89}$ $r = 0.191\ P^{0.82}$

TA **GAP**

Fe_2O_3

$r = 0.191\ P^{0.68}$ $r = 0.212\ P^{0.65}$

TA **GAP**

Cu Chromite

$r = 0.170\ P^{0.82}$ $r = 0.177\ P^{0.80}$

TA **GAP**

BLS + Cu_2O + C-black

$r = 0.175\ P^{0.93}$ $r = 0.187\ P^{0.90}$

TA **GAP**

Sodium Borohydride (on Al_2O_3)

Among the ballistic modifiers, copper chromite appears to be the most effective while BLS + Cu_2O + C-black and sodium borohydride (on Al_2O_3) appear to be the least effective in enhancing the burn rates. Fe_2O_3 gives intermediate results. Copper chromite exhibits the best results with respect to pressure index also as revealed by the value of 0.65 – 0.68 for the composition modified by it compared to 0.8 – 0.93 for BLS + Cu_2O +

C-black, Fe_2O_3 and sodium borohydride on (Al_2O_3). Such low index values are not reported earlier in the high pressure regions (14 – 200 MPa). As expected, inclusion of ballistic modifier led to marginal reduction in F (Table 2).

Acoustic Burn Rate

TA plasticised EVA binder based formulations with 70 – 60% RDX and 10 – 20% AP exhibited stable combustion in the pressure range studied (8.8 – 10.8 MPa) with the burning rate of ~ 6 – 8 mm/s, while corresponding formulations with Estane binder did not exhibit combustion in this pressure range. GAP plasticised Estane binder based systems with 10 – 20% AP revealed stable combustion in the pressure range of 6.8 – 10.8 MPa like EVA based formulation containing 10% AP albeit with relatively lower burning rates (5 – 7 mm/s) than latter (8 – 11.5 mm/s). In case of GAP plasticised EVA based formulation with 20% AP, pressure limit of stable combustion was extended to the level of 3.4 MPa (Table 3). These results further confirm overall superior burning characteristics of EVA binder based formulation with 60% RDX and 20% AP. The pressure-burn rate relationships bring out lower pressure index value of GAP plasticised formulations (Fig. 7 & 8) in the range of 3.4 to 10.8 MPa as observed during closed vessel firings (in the pressure range of 14 to 200 MPa).

Incorporation of ballistic modifiers namely copper chromite, BLS + Cu_2O + C-black and sodium borohydride (on Al_2O_3) in TA plasticized formulations led to marginal increase in burning rates (4 – 6%). Copper chromite was relatively more effective (8-10%). In case of GAP plasticised formulation also burning rate enhancement was marginal (2-6%) with BLS + Cu_2O + C-black and sodium borohydride (on Al_2O_3) while addition of copper chromite resulted in burning rate increase to the order of 30 – 60% in the lower pressure region (3.4 – 4.9 MPa). Fe_2O_3 gave intermediate results (Table 4). As in close vessel test conducted in high pressure region, copper chromite gave the best results in terms of pressure-index (0.32 – 0.45) during acoustic burning tests in the pressure range of 3.4 – 10.8 MPa (Fig.9 & 10).

DSC

As reported earlier by the authors[9], RDX-EVA and Estane based formulations with TA as plasticizer give endotherm at 196-200°C immediately followed by an exotherm at 241-244°C with ΔH of 1753-1757 J/g. Incorporation of 10-20% AP in TA plasticized EVA and Estane formulations brought down Tm of exotherm by about 10-30 °C with increase in ΔH by ~500 - 900 J/g. Replacement of TA by GAP resulted in increase in Tm by 20°C and decrease in ΔH by 400 – 800 J/g in case of EVA based formulations while it did not have any effect on Estane based formulations (Table 5 & Fig.11-22). Inclusion of Fe_2O_3 , Cu chromite, BLS + Cu_2O + C-black, sodium borohydride (on Al_2O_3) as ballistic modifiers in the selected TA plasticizer based formulations (with 60% RDX and 20% AP) led to increase in Tm and decrease in ΔH of exotherm, while in case of GAP plasticised formulation decrease in Tm of exotherm without much effect on ΔH was observed (Table 6, Fig.23-32).

In order to generate additional information, ballistically modified propellants were subjected to TG (Table 7 and Fig.33-48). The TA plasticised formulation with 60% RDX and 20% AP gave weight loss of 90% in temperature range 180 - 210°C. Subsequent

10% weight loss was observed in the temperature range of 210 - 600°C. Ballistic modifiers based formulations also revealed more or less similar weight loss pattern. In case of GAP plasticized formulations 84% weight loss was observed in the temperature range of 180 - 240°C and subsequently 16% weight loss occurred in the temperature range of 240 - 600°C. Fe_2O_3 based formulations exhibited 85% weight loss in the temperature range 180 - 230°C. $NaBH_4$ (on Al_2O_3) and BLS + Cu_2O + C-black modified formulation exhibited 85% weight loss in the temperature range 180 - 210°C. Copper chromite based formulations revealed relatively higher weight loss (90%) in the same temperature region.

Mechanistic Approach

Authors observed during recent work[9] that, EVA and Estane based RDX formulations exhibit an endotherm at about 205°C and an exotherm at 225°C. These temperatures are close to melting and decomposition temperatures of RDX respectively, suggesting that RDX plays a major role in the decomposition process as reported by various researchers[10]. AP based TA/GAP plasticized formulations exhibited a drop in Tm and an increase in heat release suggesting that AP catalyses condensed phase reactions. These results are in line with those reported by other researchers[11] and are attributed to the intensified oxidative reactions on/near surface due to positive oxygen balance of AP.

As regards ballistically modified TA plasticized compositions, heat evolved in DSC was less and Tm was relatively higher compared to those for corresponding unmodified compositions. Much lower ΔH for Fe_2O_3 based formulation may be an outcome of the need to heat it upto ~1000°C to form the proposed active species CC – Fe_2O_3[12,13]. Although BLS and Cu_2O also need to be heated to 700 - 800°C to obtain effective catalytic species[14], it is widely reported that carbon black functions as flame holder and alongwith lead salt catalyzes interaction between NO/NO_2 and carbonaceous species near the surface leading to pronounced heat feed back to the condensed phase[15]. Copper chromite is proposed to undergo exothermic redox reactions at the propellant surface[16]. Boron hydrides act as fuel producing boron and hydrogen which readily undergo exothermic oxidation. Boron is also reported to undergo nitridation[17]. It may be suggested on the basis of the observations that the incorporation of ballistic modifiers did not influence the ΔH in DSC and weight loss pattern in TG despite burn rate enhancement that the site of catalytic action of ballistic modifiers is mainly gas phase as generally reported for AP based compositions[18]. Decrease in Tm in case of GAP plasticised formulations (unlike for TA plastisized compositions) on incorporation of ballistic modifiers suggests that these modifiers catalyse interaction between decomposition products of GAP and oxidizer decomposition species in the condensed phase as suggested by Oyumi etal[19] in case of AP – 3,3'Bis Azido Methyl Oxetane (BAMO) / Nitrato Methyl 3 – Methyl Oxetane (NMMO) propellant. Weight loss patterns observed in TG further support these reasoning.

CONCLUSION :

Inclusion of GAP results in an increase in energetics as well as burn rates and reduction in pressure index. EVA based formulations exhibit superior combustion behaviour. Inclusion of ballistic modifiers leads to further improvement in ballistics in terms of enhanced burn rates. The best results are obtained with copper chromite. It was found effective not only in lower pressure region i.e. 3.4 – 10.8 MPa but also in higher pressure region i.e. 14 – 200 MPa. Thermal and ballistic data bring out that the site of action of ballistic modifiers is basically near-surface gas phase reactions, however they appear to catalyse the condensed phase decomposition reactions involving GAP. This study establishes that TPEs have potential for application as binder for not only futuristic gun propellants but also for rocket propellants (Table 8).

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TABLE-1 : THEORETICAL AND CLOSED VESSEL RESULTS OF RDX-AP PROPELLANTS

	Estane				EVA			
	TA		GAP		TA		GAP	
PARAMETERS	10% AP	20% AP	10% AP	20% AP	10% AP	20% AP	10% AP	20% AP
Theoretical								
Flame Temp, K	2716	2824	2835	2942	2763	2869	2880	2984
Force Constant, J/g	1086	1103	1138	1139	1128	1136	1173	1181
Pmax, MPa	218	220	227	220	226	228	235	237
Mol. Wt (products), g/mol	20.8	21.4	20.8	21.5	20.3	20.9	20.4	21.0
CV Firing								
Force Constant, J/g	1072	1087	1118	1122	1114	1123	1160	1169
Pmax, MPa	245	260	257	264	228	257	247	274
β, cm/s/MPa	0.092	0.126	0.105	0.137	0.133	0.155	0.133	0.162
α	0.98	0.90	0.95	0.9	1.06	0.95	0.91	0.90
n, mole/g	0.0481	0.0466	0.04800	0.0465	0.0491	0.0477	0.0490	0.0476

TABLE-2 : CLOSED VESSEL RESULTS OF BALLISTICALLY MODIFIED 60% RDX, 20% AP PROPELLANTS WITH EVA BINDER

Parameter	EVA									
	TA					GAP				
	Nil BM	Fe_2O_3	BLS + Cu_2O + C-black	$NaBH_4$ on Al_2O_3	Cu Chromite	Nil BM	Fe_2O_3	BLS + Cu_2O + C-black	$NaBH_4$ on Al_2O_3	Cu Chromite
Force constant, J/g	1123	1102	1099	1092	1109	1169	1110	1106	1099	1115
Pmax, MPa	257	250	249	246	252	274	259	253	251	263
β, cm/s/MPa	0.155	0.183	0.170	0.175	0.191	0.162	0.191	0.177	0.187	0.212
α	0.95	0.89	0.82	0.93	0.68	0.90	0.82	0.80	0.90	0.65

TABLE-3 : STRAND BURN RATES (ACOUSTIC) OF RDX-AP PROPELLANTS

	Estane				EVA			
	TA		GAP		TA		GAP	
	10% AP	20% AP	10% AP	20% AP	10% AP	20% AP	10% AP	20% AP
Pressure, MPa	Burn rate, mm/s							
3.4	-	-	-	-	-	-	-	5.2
4.9	-	-	-	-	-	-	-	7.2
6.8	-	-	4.8	5.4	-	-	8	8.4
8.8	-	-	5.7	6.3	6.0	6.3	10.8	11.8
10.8	-	-	6.6	7.2	7.5	7.9	11.4	12.3
Pressure exponent, n	-	-	0.69	0.62	1.11	1	0.78	0.76

RDX Based Composition did not undergo combustion in the acoustic strand burner.

TABLE-4 : STRAND BURN RATES (ACOUSTIC) OF BALLISTICALLY MODIFIED AP/RDX/EVA PROPELLANTS

Burn rate, mm/s at pressure, MPa	EVA									
	TA					GAP				
	20% AP	Fe_2O_3	BLS + Cu_2O + C-black	$NaBH_4$ on Al_2O_3	Cu Chromite	20% AP	Fe_2O_3	BLS + Cu_2O + C-black	$NaBH_4$ on Al_2O_3	Cu Chromite
3.4	-	-	5.4	5.4	5.6	5.2	6.0	5.5	5.4	8.1
4.9	-	-	5.9	5.8	6.1	7.2	7.7	7.4	7.5	9.0
6.8	-	6.2	6.3	6.3	6.5	8.4	8.9	8.7	8.7	9.8
8.8	6.4	6.5	6.6	6.5	6.8	11.8	12.2	12	12.1	12.7
10.8	7.9	8.2	8.3	8.3	8.5	12.3	12.8	12.5	12.6	13.3
Pressure exponent, n	1.0	0.60	0.35	0.32	0.32	0.77	0.68	0.73	0.75	0.45

TABLE-5 : DSC RESULTS OF RDX-AP BASED PROPELLANTS

Parameters	EVA						Estane					
	TA			GAP			TA			GAP		
	Nil AP	10% AP	20% AP	Nil AP	10% AP	20% AP	Nil AP	10% AP	20% AP	Nil AP	10% AP	20% AP
Endotherm, °C	206	200	201	206	199	196	203	197	196	202	196	195
ΔH, H/g	110	257	189	173	89	58	90	116	57	87	93	68
Exotherm, °C	244	210	208	239	226	224	241	231	229	240	234	234
ΔH, J/g	1757	2247	2667	1634	1830	1837	1753	2416	2483	1648	2432	2450

TABLE-6 : DSC OF BALLISTIC MODIFIED AP/RDX/EVA PROPELLANTS

	EVA									
	TA					GAP				
	W/o Ballistic Modifier	Fe_2O_3	BLS + Cu_2O + C-black	$NaBH_4$ on Al_2O_3	Cu Chromite	w/o Ballistic Modifier	Fe_2O_3	BLS + Cu_2O + C-black	$NaBH_4$ on Al_2O_3	Cu Chromite
Endo, °C	198	200	201	200	200	197	202	199	201	200
ΔH, J/g	57	100	443	189	250	68	235	112	68	107
Exo, °	208	216	214	223	212	224	216	218	217	213
ΔH, J/g	2667	1580	2474	2361	2027	1837	1860	1844	1863	1839

TABLE-7 : TGA OF BALLISTICALLY MODIFIED AP/RDX/EVA PROPELLANTS

EVA																			
TA										GAP									
Nil BM		Fe_2O_3		BLS + Cu_2O + C-black		$NaBH_4$ on Al_2O_3		Cu Chromite		Nil BM		Fe_2O_3		BLS + Cu_2O + C-black		$NaBH_4$ on Al_2O_3		Cu Chromite	
Temp °C	WL %	Temp. °C	WL %	Temp. °C	WL %	Temp. °C	WL %	Temp. °C	WL %	Temp. °C	WL %	Temp. °C	WL %	Temp. °C	WL %	Temp. °C	WL %	Temp. °C	WL %
180-210	90	180-210	90	190-230	90	180-210	90	190-210	90	180-240	84	180-230	85	180-210	85	180-210	85	180-210	90
210-600	10	210-600	10	230-600	10	210-600	10	210-600	10	240-600	16	230-600	.15	210-600	15	210-600	15	210-600	10

WL – Weight loss
BM – Ballistic modifier

TABLE 8 : PROMISING ROCKET PROPELLANT COMPOSITION

Composition	Isp. S	Force constant (F), J/g
65% AP + 20% Al + 12% EVA + 3% TA	261	1160
65% AP + 20% Al + 12% EVA + 3% GAP	263	1175
65% AP + 20% Al + 12% Estane + 3% TA	258	1128
65% AP + 20% Al + 12% Estane + 3% GAP	260	1144
65% RDX + 20% Al + 12% EVA + 3% TA	254	1057
65% RDX + 20% Al + 12% EVA + 3% GAP	256	1067
65% RDX + 20% Al + 12% Estane + 3% TA	252	1033
65% RDX + 20% Al + 12% Estane + 3% GAP	253	1044

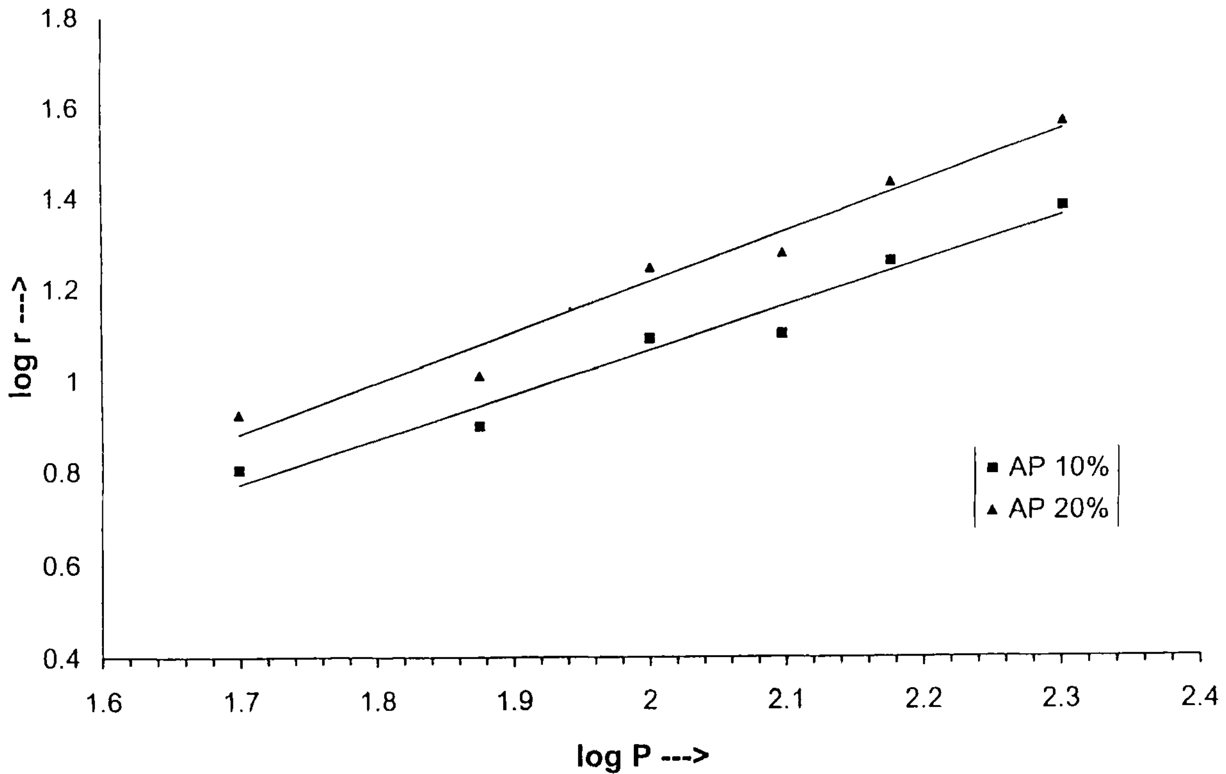


Fig 1: log r Vs log P graph of RDX / AP / EVA -TA based compositions

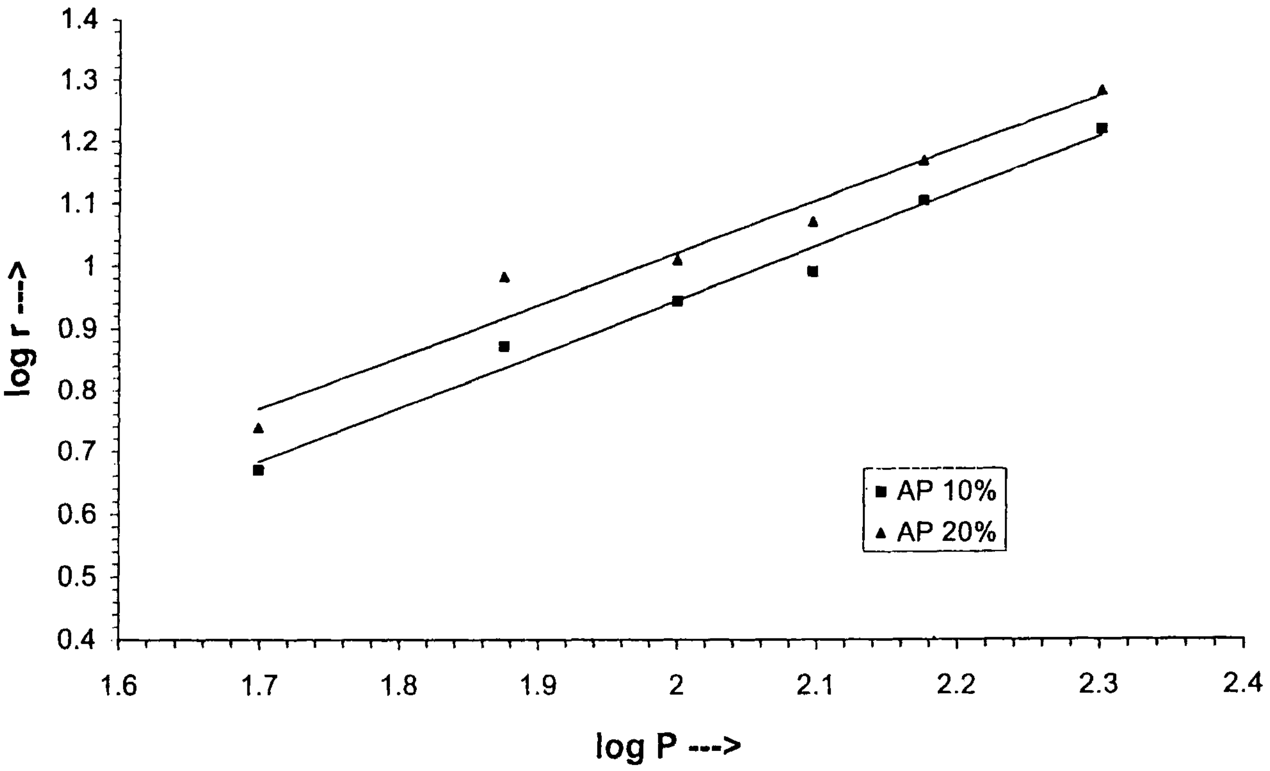


Fig 2: log r Vs log P graph of RDX / AP / EVA -GAP based compositions

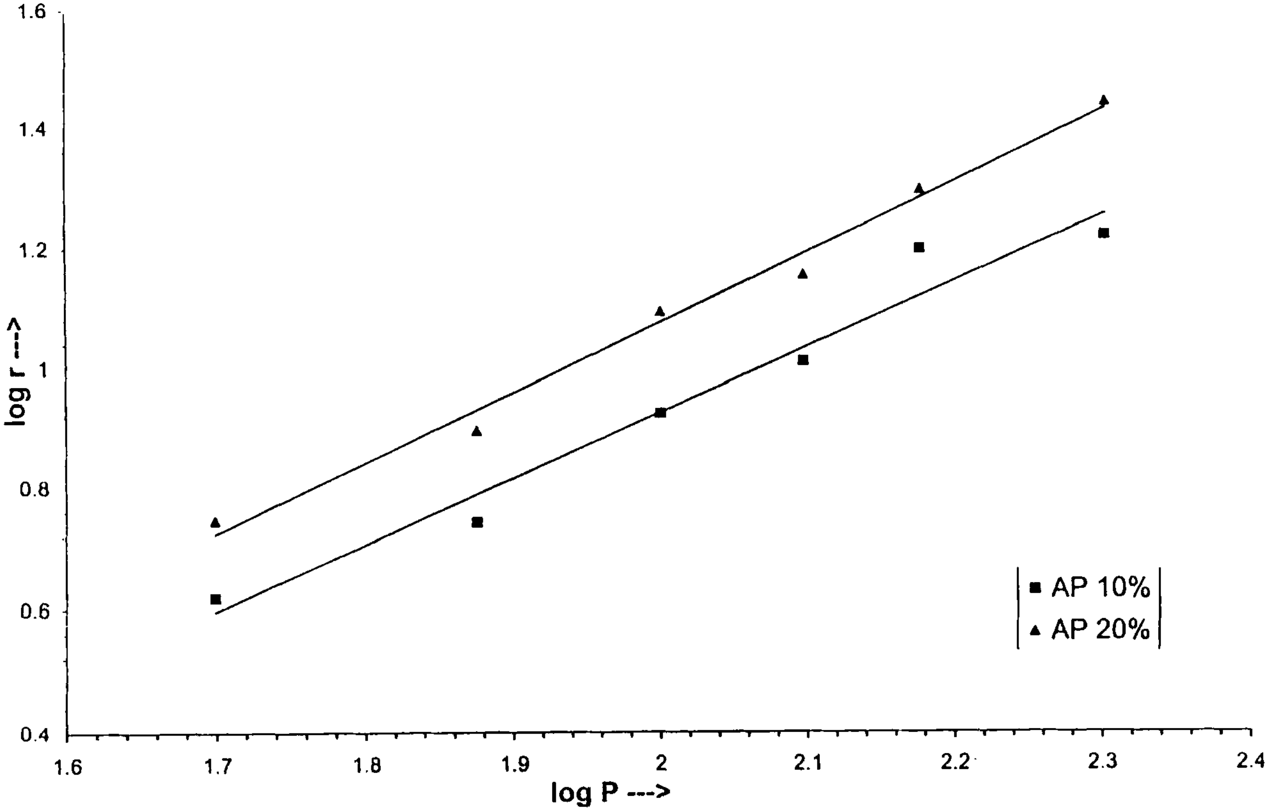


Fig 3: log r Vs log P graph of RDX / AP / Estane-TA based compositions

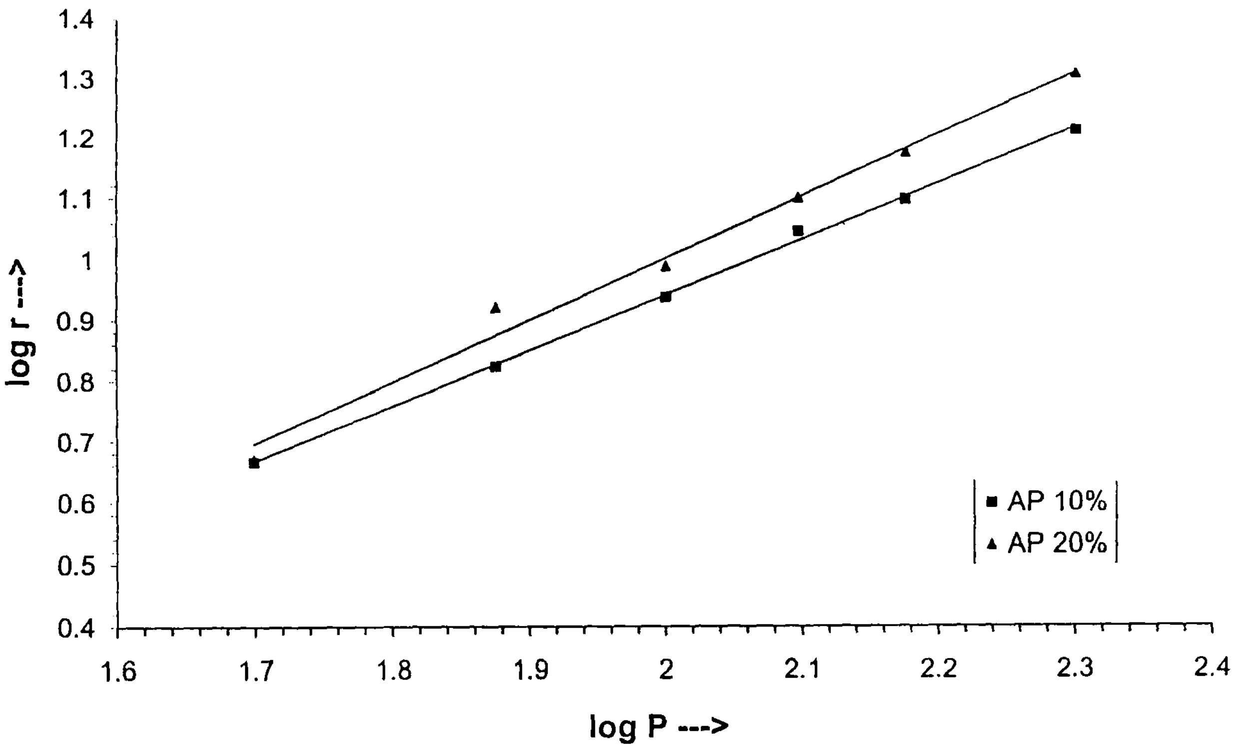


Fig 4: log r Vs log P graph of RDX / AP / Estane-GAP based compositions

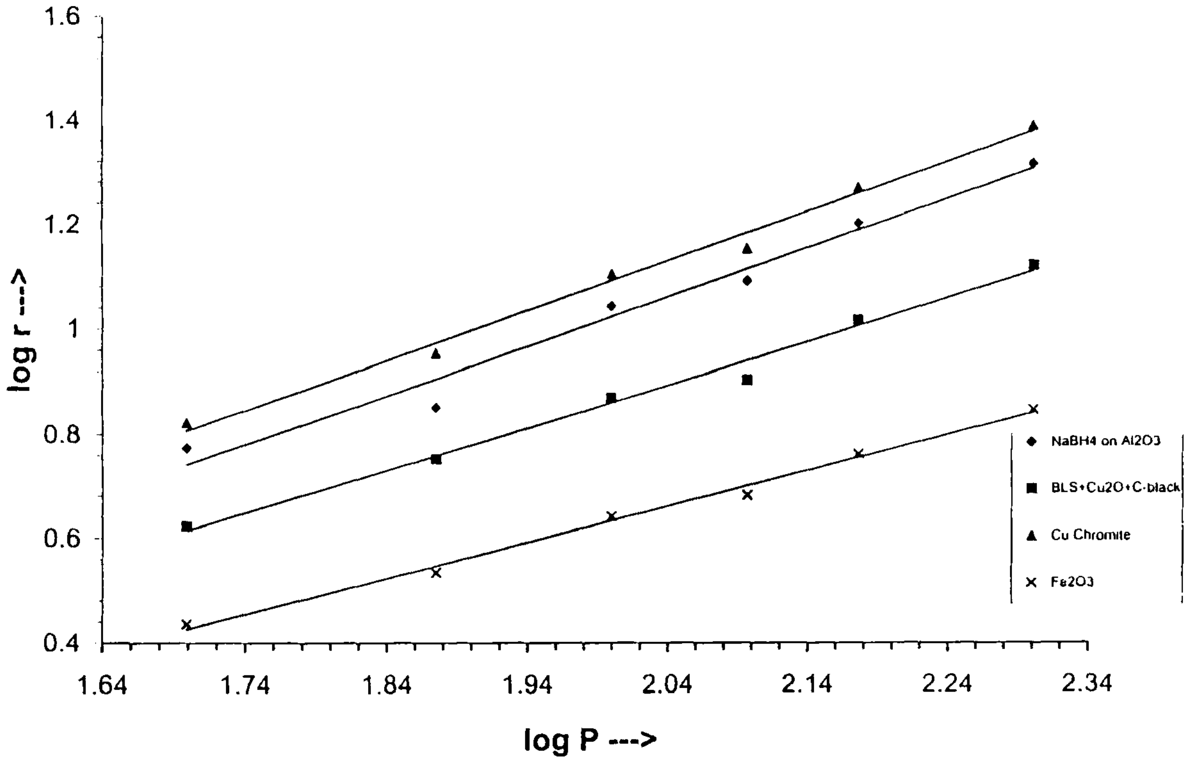
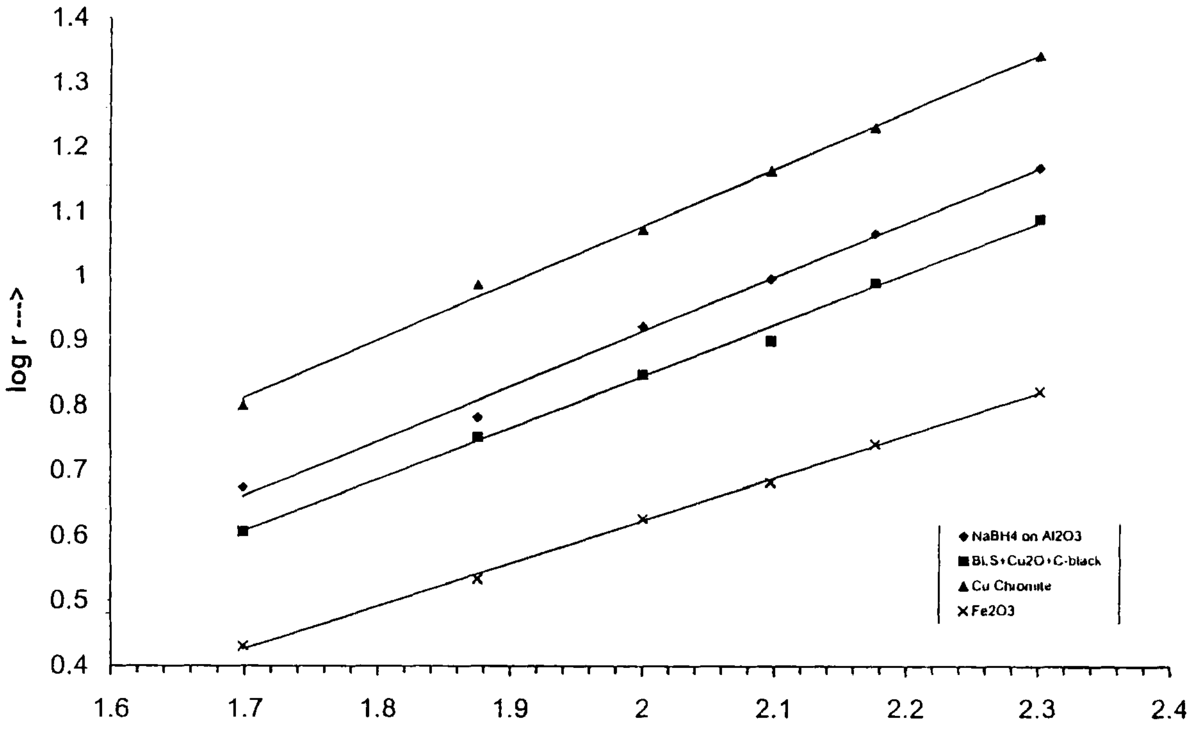


Fig 5: log r Vs log P graph of ballistically modified RDX / AP / EVA - TA based compositions



log P --->

Fig 6: log r Vs log P graph of ballistically modified RDX / AP / EVA -GAP based compositions

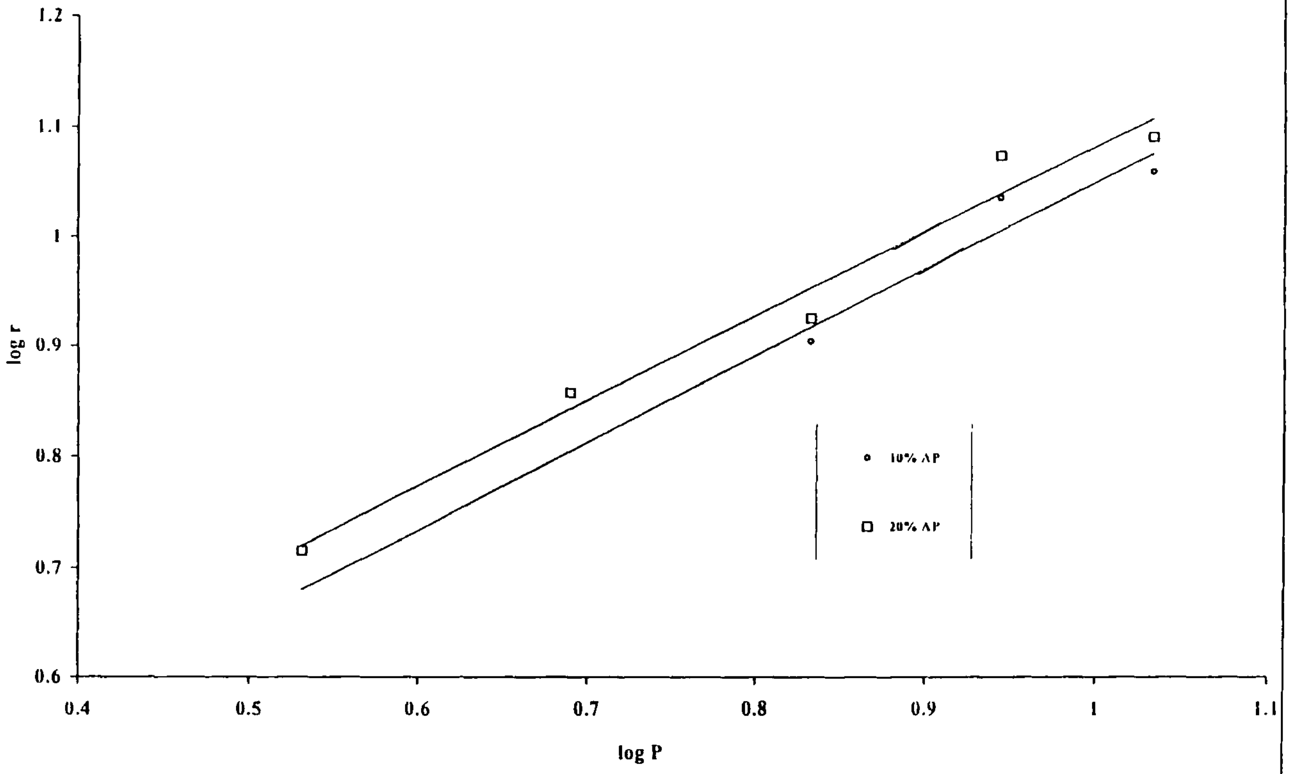


Fig.7- Pressure burn rate relationship for GAP plasticized RDX:AP propellants with EVA binder

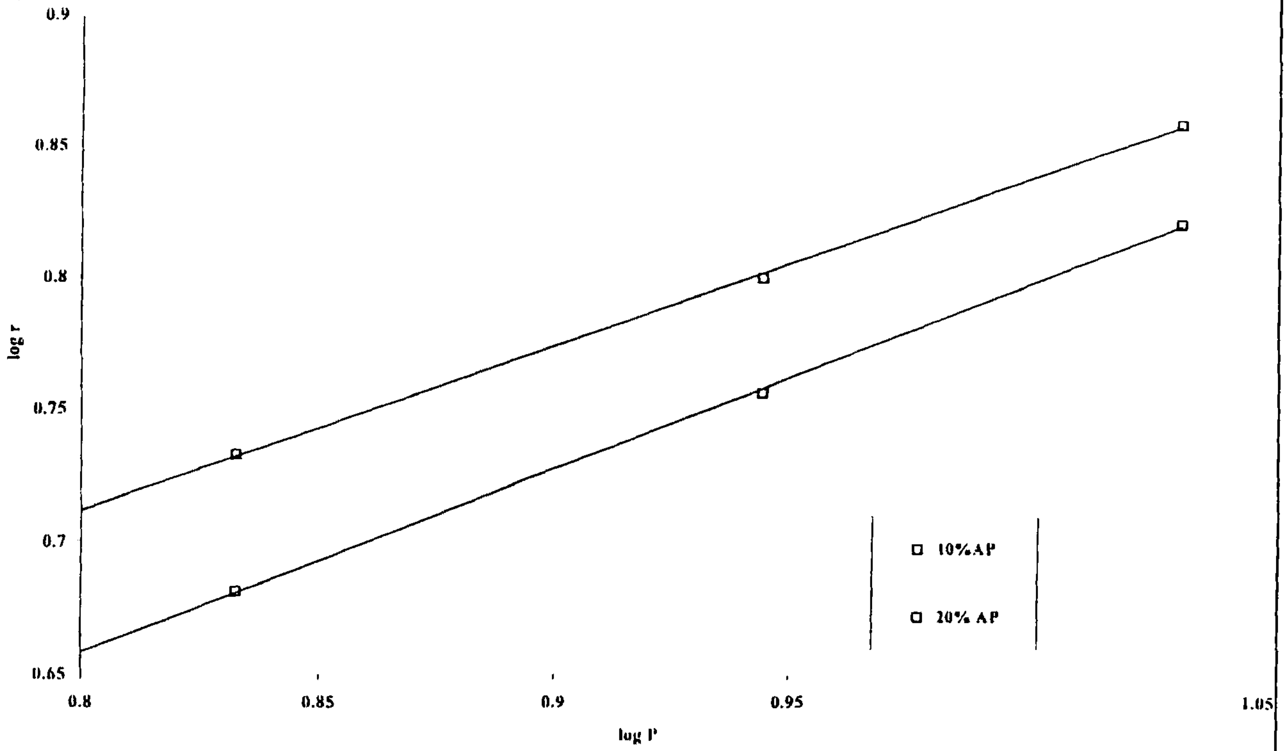


Fig. 8: Pressure burn rate relationship for GAP plasticized RDX: AP propellants with Estane binder

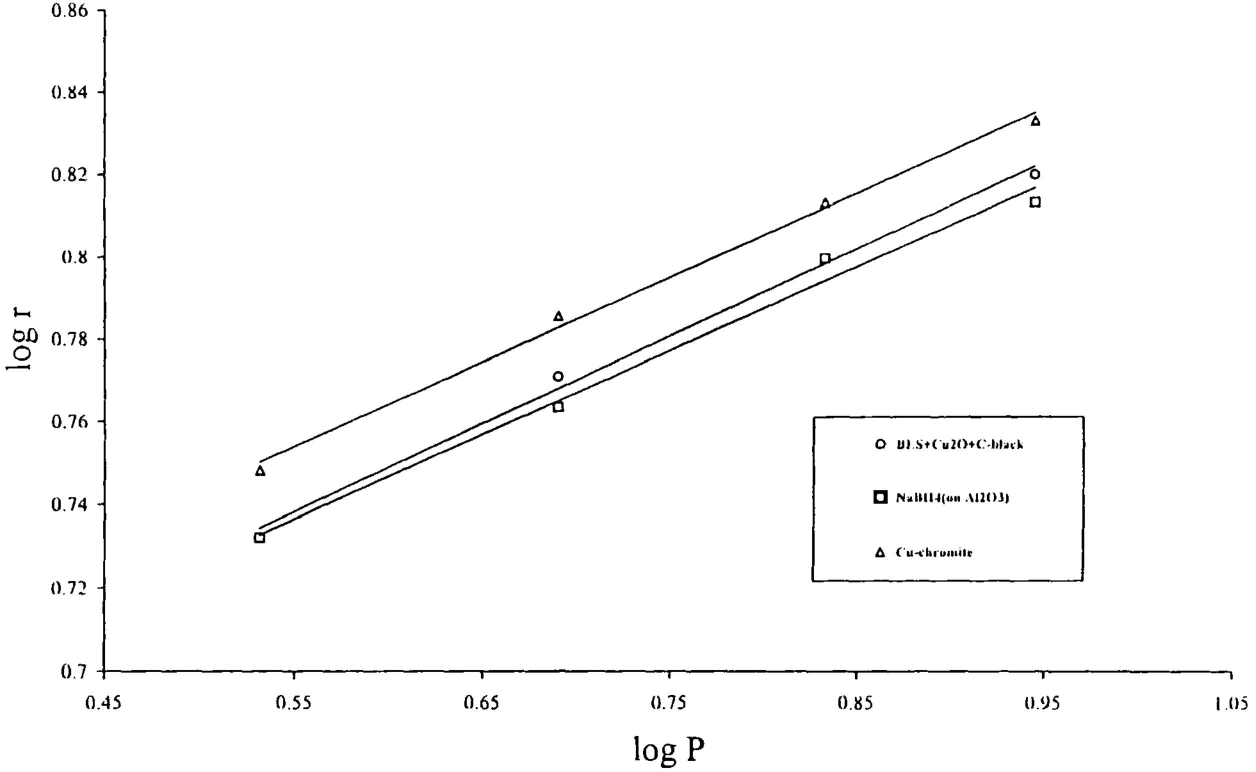


Fig.9- Pressure burn rate relationship for ballistically modified TA plasticised, EVA binder based composition.

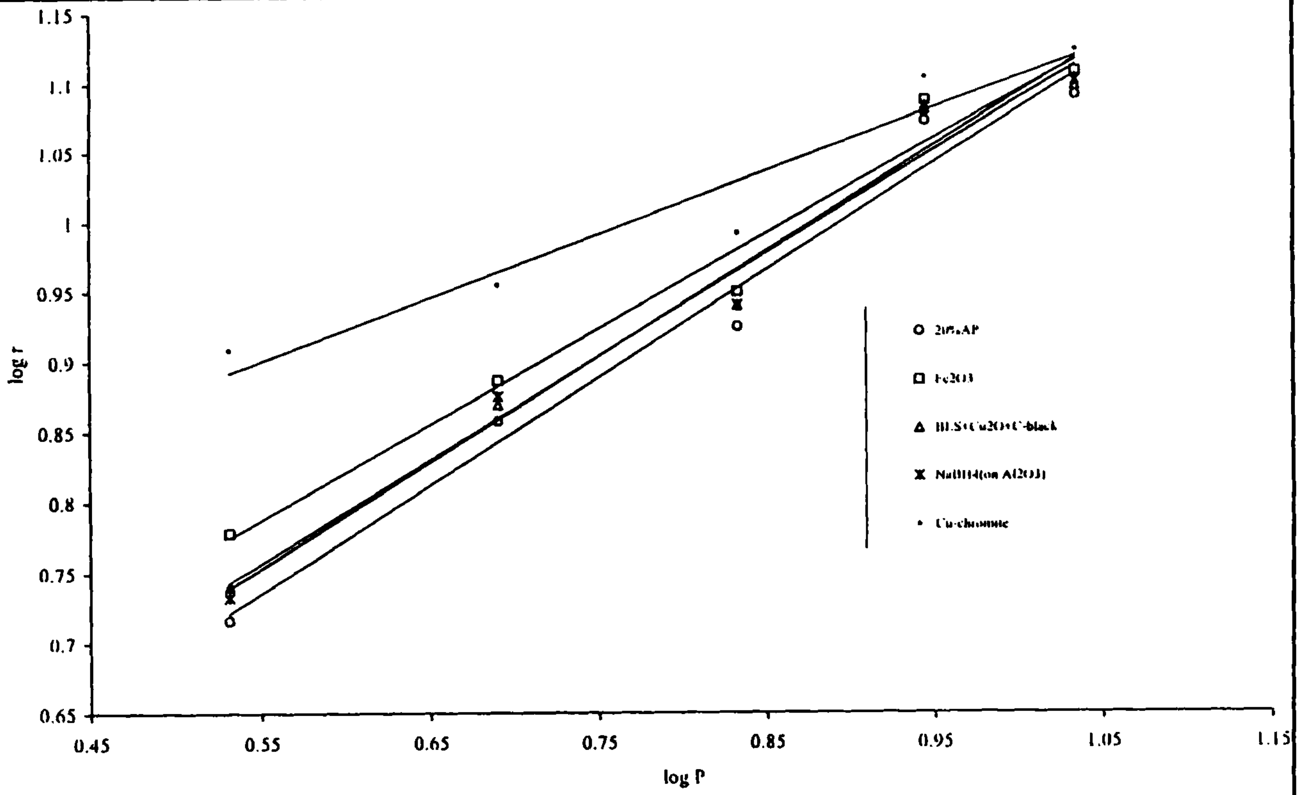


Fig.10 Pressure burn rate relationship for ballistically modified GAP plastisised, EVA binder based composition

DSC PROFILES OF RDX/AP/EVA-TA BASED PROPELLANTS

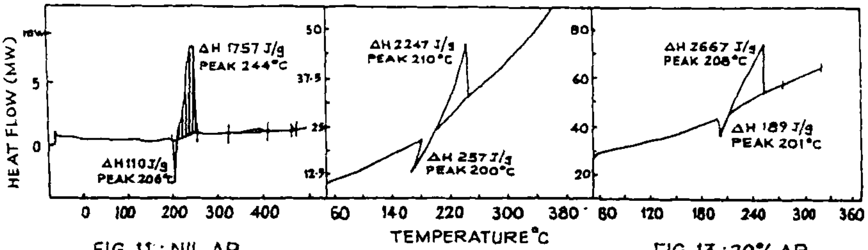


FIG. 11 : NIL AP

FIG. 12 : 10% AP

FIG. 13 : 20% AP

DSC PROFILES OF RDX/AP/EVA-GAP BASED PROPELLANTS

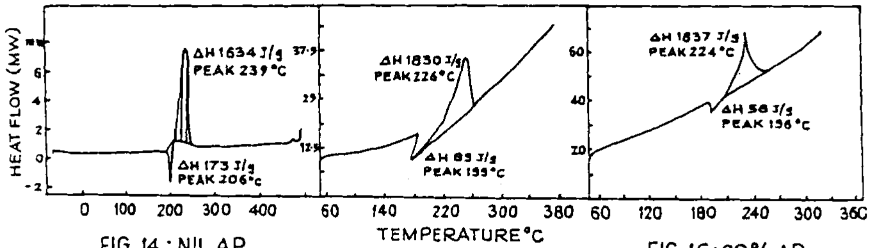


FIG. 14 : NIL AP

FIG. 15 : 10% AP

FIG. 16 : 20% AP

DSC PROFILES OF RDX/AP/ESTANE-TA BASED PROPELLANTS

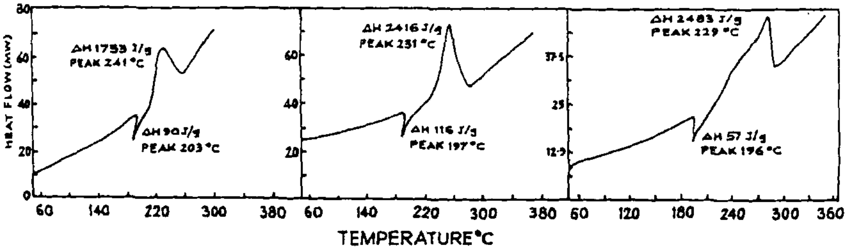


FIG.17: NIL AP

FIG. 18: 10% AP

FIG. 19: 20% AP

DSC PROFILES OF RDX/AP/ESTANE-GAP BASED PROPELLANTS

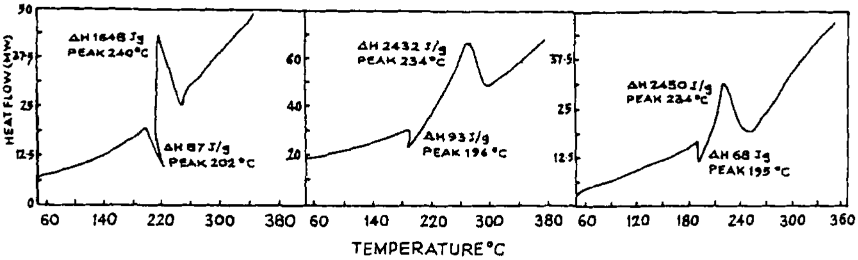


FIG.20: NIL AP

FIG.21: 10% AP

FIG.22: 20% AP

DSC OF BALLISTICALLY MODIFIED AP/RDX/EVA-TA BASED PROPELLANTS

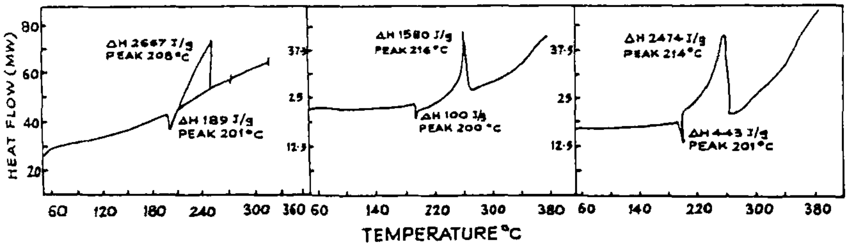


FIG.23: W/o BM FIG.24: Fe_2O_3 FIG.25: BLS+Cu_2O+C-BLACK

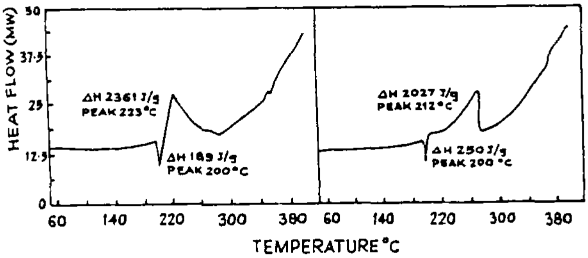
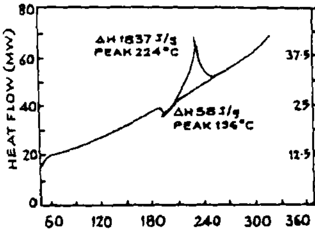
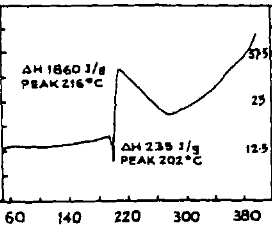
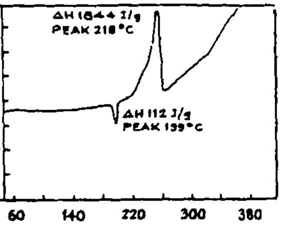


FIG.26: $NaBH_4$ on Al_2O_3 FIG.27: Cu CHROMITE

DSC OF BALLISTICALLY MODIFIED AP/RDX/EVA-GAP BASED PROPELLANTS





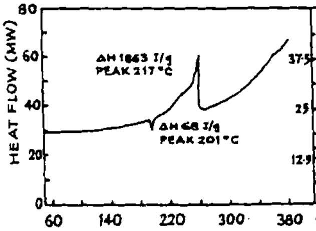


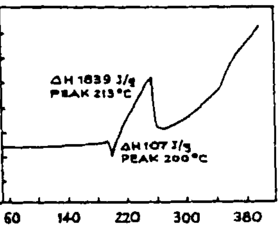
TEMPERATURE °C

FIG. 28: w/o BM

FIG.29: Fe_2O_3

FIG.30: BLS + Cu_2O + C - BLACK





TEMPERATURE °C

FIG.31 : $NaBH_4$ on Al_2O_3

FIG.32: Cu CHROMITE

TGA PROFILES OF RDX/AP/EVA-TA BASED PROPELLANTS

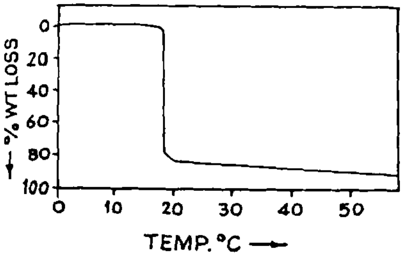


FIG.33:10% AP

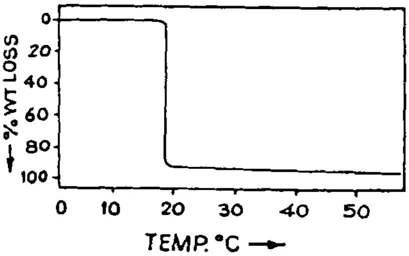


FIG.34:20% AP

TGA PROFILES OF RDX/AP/EVA-GAP BASED PROPELLANTS

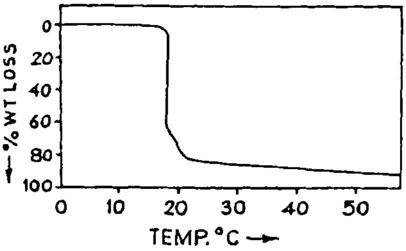


FIG.35: 10% AP

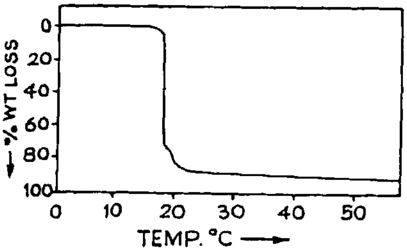


FIG.36: 20% AP

TGA PROFILES OF RDX/AP/ESTANE-TA BASED PROPELLANTS

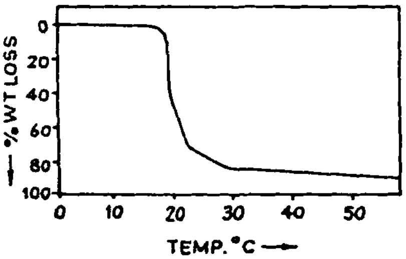


FIG.37: 10% AP

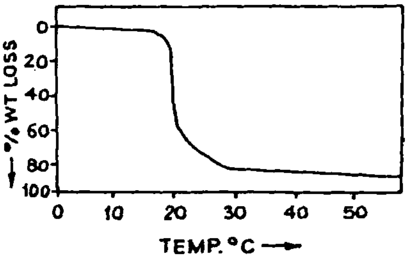


FIG.38: 20% AP

TGA PROFILES OF RDX/AP/ESTANE - GAP BASED PROPELLANTS

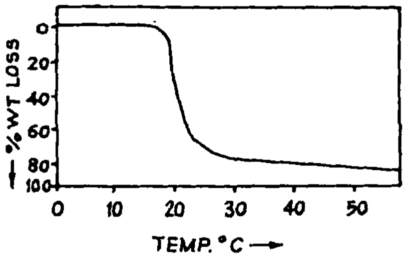


FIG.39: 10% AP

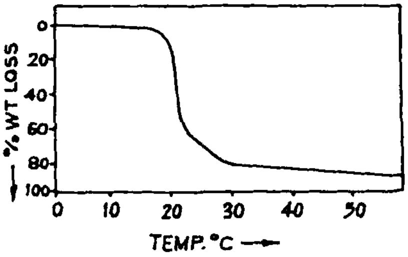


FIG.40: 20% AP

TGA PROFILES OF BALLISTICALLY MODIFIED AP/RDX/EVA-TA BASED PROPELLANTS

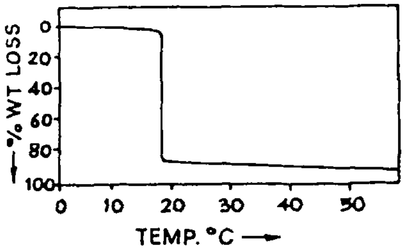


FIG.41: Fe_2O_3

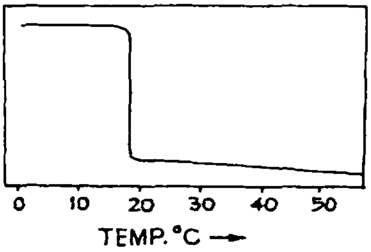


FIG.42: BLS + Cu_2O + C-BLOCK

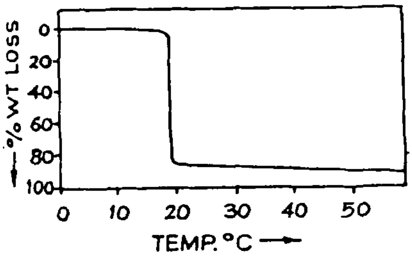


FIG.43: $NaBH_4$ on Al_2O_3

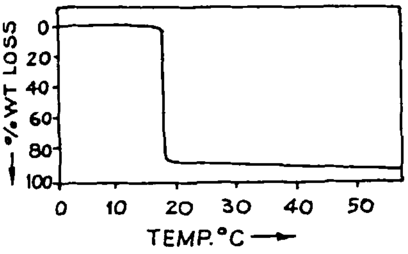


FIG.44: Cu CHROMITE

TGA PROFILES OF BALLISTICALLY MODIFIED AP/RDX/EVA-GAP BASED PROPELLANTS

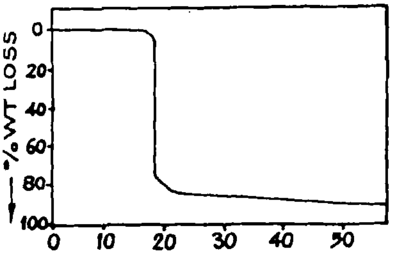


FIG.45: Fe_2O_3

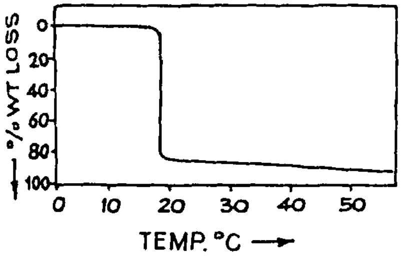


FIG.46: BLS + Cu_2O + C-BLOCK

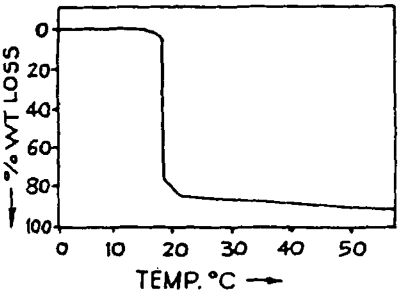


FIG.47: $NaBH_4$ on Al_2O_3

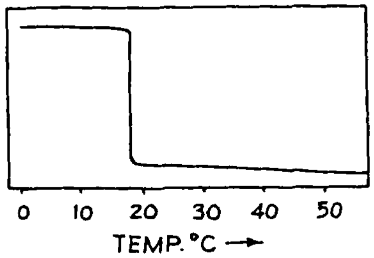


FIG.48: Cu CHROMITE