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## Addition of RDX/HMX on the Ignition Behaviour of Boron-Potassium Nitrate Pyrotechnic Charge

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### ABSTRACT

Boron-potassium nitrate ( $B-KNO_3$ ) (25/75) is a well-known pyrotechnic composition which finds application as energy-release system for small-calibre rockets and pyrogen igniters for larger motors. The decomposition of the oxidiser in this composition is endothermic which can be activated by the addition of high explosives, which decompose exothermically. This paper describes the influence of two nitramine explosives, RDX and HMX, on the ignition characteristics of  $B-KNO_3$  composition using thermogravimetry, differential scanning calorimetry, heat and pressure output measurements. Different compositions were prepared by varying the amount of RDX/HMX from 10 per cent to 50 per cent. Thermal studies on the  $B-KNO_3$ /high explosive mixtures reveal that these undergo two-stage decomposition. The first stage corresponds to the decomposition of high explosive and the second stage corresponds to that of the reaction between  $B$  and  $KNO_3$ . Kinetic parameters were calculated for both the stages of TG curves using Coats-Redfern and Mac Callum-Tanner methods. Ignition temperature of  $B-KNO_3$  decreases on the addition of RDX/HMX while the onset of RDX or HMX decomposition is not significantly affected by  $B-KNO_3$ . The pressure output of  $B-KNO_3$  increases on adding RDX/HMX. The heat output of  $B-KNO_3$  is not much affected by the addition of RDX or HMX, even though the heat of explosion of RDX and HMX are low. This is due to the reaction between the combustion products of RDX/HMX and reaction products of  $B-KNO_3$  to form more exothermic products like  $B_2O_3$ , releasing extra heat. The flame temperature of the charge increases while the average molecular weight of the products of combustion decreases as the RDX/HMX content increases. Thus, the charge, on addition of RDX or HMX, produces higher pressure output, maintaining the heat output at comparable levels.

**Keywords:** Pyrotechnic composition, boron/potassium nitrate, thermal decomposition, ignition behaviour, pyrotechnic change, RDX/HMX, fuel-oxidiser mixture

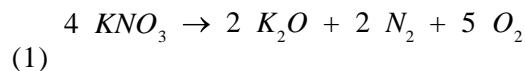
### 1. INTRODUCTION

Pyrotechnic compositions are intimate mixtures of fuels and oxidisers. Boron-potassium nitrate ( $B-KNO_3$ )(25/75) is one such composition extensively used in space ordnance for many ignition applications<sup>1,2</sup>.

In this composition, boron acts as the fuel and potassium nitrate the oxidiser. The exothermic reaction between boron and potassium nitrate occurs at the surface of boron particles in molten potassium nitrate at about 730 K. The major products of reaction between  $B$  and  $KNO_3$  are  $BN(s)$ ,  $B_2O_3$ ,  $BO$ ,  $B_2O_2$

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and  $KBO_2$ . Potassium nitrate has a melting point of 607 K. It remains in the melt form without undergoing decomposition up to about 820 K and then undergoes decomposition as follows:



This reaction is strongly endothermic by 316 kJ/mol. The decomposition of  $KNO_3$  can be activated by adding a high explosive, which decompose exothermically. In the present study, the effect of adding two structurally similar nitramine explosives, viz., cyclotrimethylenetrinitramine (RDX) and cyclotetramethylenetetranitramine (HMX) on the ignition behaviour of  $B-KNO_3$  has been studied. The addition of these explosives to  $B-KNO_3$  can increase the gas volume and pressure output of the charge without sacrificing the heat output and the amount of solid products can be reduced. Since both explosives decompose exothermically at lower temperatures, the reaction temperature of  $B-KNO_3$  is brought down.

## 2. EXPERIMENTAL

### 2.1 Materials

Boron was procured from K.V. Corporation, Japan with a purity of  $\sim 95$  per cent and an average particle size of 1  $\mu m$ .  $KNO_3$  was procured from S D Fine Chemicals Ltd, Boisar, with a purity of  $\sim 99.5$  per cent. It was ground in a pot mill and the fraction passing through 106  $\mu m$  sieve and retained over 63  $\mu m$  was collected (average particle size 75  $\mu m$ ). RDX and HMX obtained from the Ordnance Factory, Bhandara, having purity  $>99.9$  per cent were sieved and fraction having the same range of particle size as  $KNO_3$  was chosen.

### 2.2 Methods

Boron/potassium nitrate (25/75) composition was prepared with accurate weight of the ingredients and mixing these by sieving through a 125  $\mu m$  sieve five-times. This composition was then mixed with required amount of high explosive to prepare five compositions in which the RDX or HMX percentage was varied from 10 to 50. TG and DSC of these

compositions were done using Perkin Elmer TGA 7 and DSC 7 in flowing argon medium (30 ml/min) at 5 k/min. Sample mass was restricted to 2 mg to 3 mg. Calorimetric values were determined by burning nearly 1 g charge in a Parr bomb calorimeter model 1261 in argon atmosphere at 2.8 MPa. The products of reaction were collected for IR studies.

### 2.3 Characterisation

Pressure tests on the charges were conducted by firing 0.40 g charge filled in M16 x 1 cartridge into a closed vessel of 48 cc. Pressure was recorded as a function of time using a piezoresistive pickup. Five tests were done for each composition and the average value taken. Friction sensitivity of the compositions was determined using Julius Peters equipment and impact sensitivity using drop weight method.

Two integral methods of Coats-Redfern<sup>3</sup> and MacCallum-Tanner<sup>4</sup> were used to evaluate the kinetic parameters from the TG curves.

#### 2.3.1 Coats-Redfern Method

$$(2)$$

#### 2.3.2 Mac Callum-Tanner Method

$$(3) \quad \log[g(\alpha)] = \log\left(\frac{AE}{\phi R}\right) - 0.483E^{0.435} - [(0.449 + 0.217E)10^3/T]$$

Here,  $E$  is the activation energy,  $R$  is the universal gas constant,  $\phi$  is the heating rate, and  $A$  is the pre-exponential factor. The term  $g(\alpha)$  is defined as

$$g(\alpha) = \frac{1 - (1 - \alpha)^{1-n}}{(1-n)}$$

when  $n \neq 1$  and  $g(\alpha) = -\ln(1-\alpha)$  when  $n = 1$ .

The left hand side of the equation was plotted against  $1/T$ . The value of  $n$ , for which best fit was obtained, was chosen as the order parameter. The

activation energy  $E$  and pre-exponential factor  $A$  were calculated from the values of slope and intercept, respectively.

### 3. RESULTS & DISCUSSION

#### 3.1 Thermogravimetric Studies

The reaction between boron and potassium nitrate is exothermic and takes place in the temperature range 718 K to 828 K with DTG peak at 788 K. The corresponding weight loss observed is 19.6 per cent. RDX undergoes complete decomposition in the range 478 K to 533 K with peak temperature at 520 K as reported in literature<sup>5</sup>. All the  $B-KNO_3$ /RDX mixes undergo reaction in two stages. The first stage corresponds to the decomposition of RDX while the second stage corresponds to the reaction between boron and potassium nitrate. The weight loss observed in the first stage corresponds to the complete decomposition of RDX and that in the second stage corresponds to the partial escape of  $K_2O$ . TG data are given in Table 1.

Kinetic parameters calculated using both methods gave comparable values for activation energy and pre-exponential factor. Activation energy obtained for decomposition of RDX is nearly 207 kJ/mol, which is comparable with the literature values<sup>6</sup>. The first stage of  $B-KNO_3$ /RDX 50/50 composition corresponding to RDX decomposition gave activation energy of nearly 150 kJ/mol, which decreased to about 132 kJ/mol as the percentage of boron/

potassium nitrate was increased to 90 per cent. Similarly, the value of  $\ln A$  also decreased from 47 to 30.3. The value of  $n$  lies between 0.7 and 0.9 for RDX. The values of kinetic parameters are given in Tables 2 and 3.

Activation energy and  $\ln A$  values for  $B-KNO_3$  are 363 kJ/mol and 54, respectively. The value of activation energy of second stage decreased on progressive addition of RDX, indicating that RDX activated the reaction between  $B$  and  $KNO_3$ . The value becomes 310 kJ/mol on addition of 50 per cent RDX.

The effect of adding HMX is similar to that of RDX. The decomposition of HMX started at about 555 K with a DTG peak at 564 K. TG data of  $B-KNO_3$ /HMX compositions are given in Table 4.

The weight loss observed is the same as in the case of RDX addition. In the first stage corresponding to the decomposition of HMX, weight loss occurred so rapidly that the curve was steep. Kinetics of both stages were computed using the two methods mentioned earlier. As in the case of RDX addition, activation energy of  $B-KNO_3$  decreased with addition of HMX. The value reduced to nearly 316 kJ/mol for composition with 50 per cent HMX. The value of  $n$  lies between 0.1 and 0.5. The activation energy for HMX decomposition is 224 kJ/mol, which is comparable to literature values and it reduces with increase in the amount of  $B-KNO_3$ . Here also  $E/\ln A$  values were computed and found to be constant.

Table 1. Thermogravimetric data of B-KNO<sub>3</sub>/RDX compositions

$B-KNO_3$ /RDX Wt %	Stage I				Stage II				
	$T_i$ (K)	$T_f$ (K)	$T_p$ (K)	Wt loss (%)	$T_i$ (K)	$T_f$ (K)	$T_p$ (K)	Wt loss (%)	
								Expected	Observed
100/0	-	-	-	-	728	828	798.4		19.6
90/10	423	508	495.2	10.4	723	818	794.5	17.6	17.3
80/20	428	511	496.1	19.5	718	813	774.0	15.7	15.3
70/30	430	518	502.6	30.4	716	808	767.6	13.7	13.7
60/40	433	521	503.0	39.3	714	808	761.4	11.8	12.7
50/50	433	523	503.4	50.3	713	803	740.2	9.8	10.6
0/100	478	533	520.0	100	-	-	-	-	-

**Table 2. Kinetic parameters of first stage decomposition of  $B-KNO_3$ /RDX compositions calculated using Coats-Redfern and Mac Callum-Tanner methods**

$B-KNO_3$ /RDX Wt. (%)	Coats-Redfern method				Mac Callum-Tanner method			
	$E$ (kJ/mol)	lnA	$r^2$	$n$	$E$ (kJ/mol)	lnA	$r^2$	$n$
90/10	131.8 ± 1.2	30.3	0.9994	0.2	131.3 ± 11.2	30.1	0.9968	0.3
80/20	135.3 ± 2.1	31.9	0.9963	0.6	135.9 ± 10.7	31.9	0.9972	0.6
70/30	139.4 ± 3.3	32.7	0.9929	0.7	138.9 ± 10.4	32.3	0.9985	0.4
60/40	145.1 ± 3.2	33.8	0.9931	0.8	145.7 ± 10.6	33.7	0.9981	0.6
50/50	150.1 ± 2.9	35.0	0.9939	0.8	152.4 ± 10.4	35.3	0.9985	0.7
0/100	206.6 ± 5.1	47.0	0.9985	0.8	204.0 ± 16.2	46.4	0.9956	0.9

**Table 3. Kinetic parameters of second stage decomposition of  $B-KNO_3$ /RDX compositions calculated using Coats-Redfern and Mac Callum-Tanner methods**

$B-KNO_3$ /RDX Wt. (%)	Coats-Redfern method				Mac Callum-Tanner method			
	$E$ (kJ/mol)	lnA	$r^2$	$n$	$E$ (kJ/mol)	lnA	$r^2$	$n$
100/0	362.8 ± 3.0	54.3	0.9998	0.4	362.3 ± 11.0	54.8	0.9997	0.4
90/10	346.5 ± 6.3	50.5	0.9947	0.3	345.0 ± 13.6	50.8	0.9971	0.3
80/20	335.3 ± 6.9	49.7	0.9932	0.4	335.4 ± 14.9	50.2	0.9954	0.3
70/30	329.1 ± 7.2	48.9	0.9952	0.1	328.3 ± 16.4	49.2	0.9931	0.3
60/40	322.2 ± 4.5	47.7	0.9975	0.4	321.6 ± 11.6	48.0	0.9990	0.2
50/50	311.3 ± 4.2	46.2	0.9980	0.2	312.1 ± 12.7	46.7	0.9983	0.1

**Table 4. TG data of  $B-KNO_3$ /HMX compositions**

$B-KNO_3$ /HMX Wt (%)	Stage I				Stage II				
	$T_i$ (K)	$T_f$ (K)	$T_p$ (K)	Wt loss %	$T_i$ (K)	$T_f$ (K)	$T_p$ (K)	Wt loss (%)	
								Observed	Expected
100/0	-	-	-	-	728	828	798.4	19.6	-
90/10	523	563	560.0	10.3	728	823	795.0	17.1	17.6
80/20	523	564	560.2	20.8	728	818	792.4	15.8	15.7
70/30	543	565	561.9	30.9	727	818	788.5	14.0	13.7
60/40	543	568	562.9	41.1	727	813	781.8	12.5	11.7
50/50	548	569	563.8	51.7	726	808	773.1	11.2	9.8
HMX	555	570	564	100	-	-	-	-	-

Kinetic parameters are given in Tables 5 and 6.

### 3.2 Differential Scanning Calorimetric Studies

The DSC peak temperatures of  $B-KNO_3$ /RDX and  $B-KNO_3$ /HMX mixes are given in Table 7. DSC curve of RDX showed melting at approx

479 K, followed by decomposition. DSC curve of  $B-KNO_3$  showed endotherm corresponding to the phase transition of potassium nitrate from orthorhombic to trigonal structure at approx 403K.

Endothermic peak at 612 K indicated the phase change in  $KNO_3$  from crystalline form to liquid,

followed by exotherm corresponding to the reaction between *B* and KNO<sub>3</sub> at approx 799 K. On addition of RDX, the peak temperature corresponding to the reaction between *B* and KNO<sub>3</sub> shifted to lower side in almost a linear fashion. The composition with 50 per cent RDX ignited at 738 K, which is almost 61° lower than the reaction temperature of *B-KNO<sub>3</sub>* charge. However, the decomposition

temperature of RDX is not significantly affected by the presence of *B-KNO<sub>3</sub>*.

DSC of HMX showed an endotherm at about 483 K, which corresponds to the polymorphic transformation<sup>7</sup> from β to δ phase. It undergoes complete decomposition at about 551 K with peak at 553 K. The addition of HMX lowered the reaction

**Table 5. Kinetic parameters of first stage decomposition of *B-KNO<sub>3</sub>/HMX* compositions calculated using Coats-Redfern and Mac Callum-Tanner methods**

<i>B-KNO<sub>3</sub>/HMX</i> Wt (%)	Coats-Redfern method				Mac Callum-Tanner method			
	<i>E</i> (kJ/mol)	lnA	<i>r</i> <sup>2</sup>	<i>n</i>	<i>E</i> (kJ/mol)	lnA	<i>r</i> <sup>2</sup>	<i>n</i>
90/10	156.3 ± 6.1	31.7	0.9804	0.1	149.6 ± 12.9	24.3	0.9896	0.1
80/20	171.2 ± 5.7	34.6	0.9859	0.1	171.2 ± 13.2	28.6	0.9913	0.1
70/30	182.6 ± 3.6	36.6	0.9943	0.3	184.5 ± 12.8	31.1	0.9933	0.3
60/40	192.1 ± 3.2	39.9	0.9972	0.1	192.2 ± 12.1	34.2	0.9970	0.3
50/50	212.3 ± 5.7	44.4	0.9942	0.5	212.8 ± 14.5	38.8	0.9945	0.6
0/100	222.3 ± 3.8	50.2	0.9993	0.8	224.3 ± 11.6	45.6	0.9993	0.9

**Table 6. Kinetic parameters of second stage decomposition of *B-KNO<sub>3</sub>/HMX* compositions calculated using Coats-Redfern and Mac Callum-Tanner method**

<i>B-KNO<sub>3</sub>/HMX</i> Wt %	Coats-Redfern method				Mac Callum-Tanner method			
	<i>E</i> (kJ/mol)	lnA	<i>r</i> <sup>2</sup>	<i>n</i>	<i>E</i> (kJ/mol)	lnA	<i>r</i> <sup>2</sup>	<i>n</i>
100/0	362.8 ± 3.0	54.3	0.9998	0.4	362.3 ± 11.0	54.8	0.9997	0.4
90/10	353.0 ± 6.6	51.3	0.9951	0.5	352.4 ± 16.2	51.6	0.9947	0.3
80/20	343.4 ± 8.4	49.8	0.9929	0.3	343.8 ± 16.2	50.3	0.9956	0.1
70/30	336.1 ± 5.3	49.0	0.9963	0.4	337.7 ± 10.9	49.6	0.9991	0.1
60/40	326.5 ± 13.7	47.7	0.9879	0.4	329.7 ± 14.2	48.6	0.9991	0.3
50/50	311.9 ± 8.1	45.7	0.9927	0.2	316.0 ± 16.2	46.7	0.9947	0.1

**Table 7. DSC peak temperatures of *B-KNO<sub>3</sub>/RDX* and *B-KNO<sub>3</sub>/HMX* compositions**

<i>B-KNO<sub>3</sub>/RDX</i> Wt %	DSC peak temp. (K)		<i>B-KNO<sub>3</sub>/HMX</i> Wt %	DSC peak temp. (K)	
	Stage I	Stage II		Stage I	Stage II
100/0		798.9	100/0		798.9
90/10	492.4	794.6	90/10	550.1	795.9
80/20	498.2	775.6	80/20	550.7	793.1
70/30	500.1	766.0	70/30	551.3	789.3
60/40	501.1	763.6	60/40	551.9	782.1
50/50	502.5	737.8	50/50	552.1	775.0
0/100	515.7	-	0/100	552.7	-

temperature of  $B-KNO_3$ . Addition of 50 per cent HMX decreases the reaction temperature by  $23^\circ$ . However, the effect is less pronounced compared to RDX addition because RDX decomposes at a lower temperature as compared to HMX.

### 3.3 Heat Output

The heat output of  $B-KNO_3$  charge is nearly 6520 J/g. This is close to the theoretical value of 6690 J/g. The heat of explosion of RDX and HMX were 5350 J/g and 5425 J/g, respectively, which closely resembled the theoretical value. The heat output of  $B-KNO_3$  is not significantly affected by the addition of these explosives. The value remains constant at about 6480 J/g. This is due to the reaction between the combustion products of  $B-KNO_3$  with that of RDX/HMX. Boron combines with the combustion products of RDX/HMX to form more exothermic  $B_2O_3$  instead of  $BN$ , liberating extra heat. Addition of both RDX and HMX has the same effect on the heat output of  $B-KNO_3$ . However, the heat output of  $B-KNO_3$ /HMX compositions are slightly on the higher side. This may be due to the higher heat output of HMX compared to RDX. The heat output values are given in Table 8.

### 3.4 Product Analysis

The products of reaction and thermodynamic parameters of  $B-KNO_3$  and its mixes with RDX and HMX were theoretically predicted using a computer program COSMOS. The products of reaction between  $B$  and  $KNO_3$  are  $BN(s)$ ,  $B_2O_3$ ,  $B(l)$ ,  $BO$ ,  $B_2O_2$ ,  $KBO_2$ , etc, while the decomposition products of RDX and HMX are  $CO$ ,  $H_2O$ ,  $N_2$ ,  $CO_2$ ,  $H$ ,  $H_2$ ,  $O_2$ ,  $NO$ , etc. The major products of reaction between  $B-KNO_3$  and RDX/HMX are  $BN(s)$ ,  $B_2O_3$ ,  $B(l)$ ,  $BO$ ,  $B_2O_2$ ,  $KBO_2$ ,  $CO$ ,  $CO_2$ ,  $HBO_2$  and  $H_2O$ . Addition of RDX or HMX gives similar distribution of products because of the similarity in their structures and the same oxygen-to-fuel ratio.

On the addition of these high explosives, the products become more gaseous, leading to increased gas volume and higher pressure output. The amount of solid  $BN$  and liquid  $B$  decreases, and for the composition with 40 per cent or 50 per cent explosive,

**Table 8. Calorimetric values of B-KNO<sub>3</sub>/RDX and B-KNO<sub>3</sub>/HMX compositions**

Wt (%)	Cal value (J/g)	
	$B-KNO_3$ /RDX	$B-KNO_3$ /HMX
100/0	6570	6570
90/10	6460	6670
80/20	6510	6602
70/30	6418	6699
60/40	6493	6615
50/50	6544	6619
0/100	5376	5440

these disappear. This is because  $B$  and  $BN$  react with the combustion products of RDX or HMX to form  $B_2O_3$ . The amount of  $KBO_2$  is found to decrease while the amount of  $B_2O_3$ ,  $HBO_2$ , and  $H_2O$  increases. The amount of  $CO$  is increasing linearly with the addition of RDX. As a whole, it can be said that the amount of gaseous products are increasing while the amount of solid and liquid products are decreasing. The variations of product concentration with addition of RDX at equilibrium pressure of 20 atm are given in Table 9.

The thermodynamic parameters of  $B-KNO_3$ /RDX mixes are given in Table 10. The average molecular weight of the products of  $B-KNO_3$  reaction is 66.76 and the gas volume is 301.3 ml/g. The average molecular weight of the products decreased with the progressive addition of RDX or HMX, and for composition with 50 per cent RDX or HMX, it is reduced to almost 33 and gas volume increased to 678 ml/g. Flame temperature of the parent composition is nearly 2910 K, which increased to about 3150 K on addition of 50 per cent nitramine explosive.

### 3.5 Pressure Output

The pressure output of  $B-KNO_3$  charge is approx 2.9 kg/cm<sup>2</sup>. The pressure output increased linearly to about 5.8 MPa with the progressive addition of RDX/HMX to 50 per cent. This is because of the increase in the amount of gaseous products. The time to  $P_{max}$  and time to  $(dP/dt)_{max}$  values were computed and the values decreased with the addition of more and more explosive. Thus, the ignition

**Table 9. Computed products of B-KNO<sub>3</sub>/RDX mixes at equilibrium pressure of 20 atm in mol/kg**

Products		B-KNO <sub>3</sub>	B-KNO <sub>3</sub> /RDX Wt %				
			90/10	80/20	70/30	60/40	50/50
BN(s)	expected		1.3751	1.2223	1.0695	0.9167	0.7640
	observed	1.5279	1.6678	1.6292	0.4152	-	-
B <sub>2</sub> O <sub>3</sub>	expected		0.4476	0.3978	0.3481	0.2984	0.2487
	observed	0.4973	0.4714	0.4734	0.6316	1.3652	1.5352
B(l)	expected		2.5501	2.2667	1.9834	1.7000	1.4167
	observed	2.8334	1.6001	0.1267	-	-	-
BO+B <sub>2</sub> O <sub>2</sub>	Expected	-	4.1777	3.7135	3.2493	2.7851	2.3210
	observed	4.6419	5.2823	6.0313	5.6706	3.1773	1.3724
KBO <sub>2</sub>	expected		4.5104	4.0093	3.5081	3.0070	2.5058
	observed	5.0116	5.0955	4.9448	4.7938	4.3950	3.7208
CO	expected	-	3.3411	2.9699	2.5987	2.2227	1.8562
	observed	-	1.1046	2.4680	3.9641	5.3884	6.6549
CO <sub>2</sub>	expected	-	1.0782	0.9557	0.8362	0.7168	0.5973
	observed	-	-	-	-	0.0107	0.0978
H <sub>2</sub> O	expected	-	2.9632	2.6339	2.3047	1.9754	1.6462
	observed	-	-	-	0.0061	0.0564	0.5154
HBO <sub>2</sub>	observed	-	0.0424	0.0670	0.1190	0.5075	1.5352

delay is reduced by the addition of RDX/HMX. Pressure values of B-KNO<sub>3</sub>/RDX and B-KNO<sub>3</sub>/HMX mixes are given in Table 11.

### 3.6 Friction & Impact Sensitivity

Boron/potassium nitrate is a less sensitive composition with friction sensitivity > 36 kgf. On addition of RDX or HMX, the value decreases and for composition with 50 per cent RDX/HMX, it is 12.8 kgf. Similarly, the impact sensitivity values

also decrease with the addition of RDX/HMX. The impact sensitivity of RDX is 6.69 J drop energy, and for HMX, it is 7.59 J drop energy. But still the value lies within the safety limit and is safe for granulation and pelletisation purposes. The values of friction and impact sensitivity are given in Table 12.

## 4. CONCLUSIONS

The thermal decomposition of B-KNO<sub>3</sub>, RDX and HMX occurred in one stage, while the mixes of B-KNO<sub>3</sub> with RDX/HMX decomposed in two stages. The first stage corresponds to the decomposition of high explosive while the second stage corresponds to the reaction between B and KNO<sub>3</sub>. The kinetic parameters calculated using methods of Coats-Redfern and Mac Callum-Tanner gave comparable values. Activation energy and lnA of B-KNO<sub>3</sub> decreased with the addition of RDX or HMX. The DSC peak temperature corresponding to the reaction between B and KNO<sub>3</sub> is shifting to lower temperatures on progressive addition of RDX or HMX. The shift is greater in the case of RDX addition. The decomposition temperature of RDX or HMX is not significantly affected by the presence of B-KNO<sub>3</sub>. The decomposition

**Table 10. Theoretical physical parameters of B-KNO<sub>3</sub>/RDX compositions at equilibrium pressure of 20 atm**

B-KNO <sub>3</sub> /RDX Wt (%)	Av. Mol Wt.	Temp (K)	Gas volume (ml/g)	C <sub>p</sub> (J/g.K)
100/0	66.8	2910	301.3	1.1630
90/10	54.0	2923	377.5	1.2445
80/20	45.4	2932	457.2	1.3209
70/30	39.3	2964	560.2	1.3877
60/40	35.6	2989	628.5	1.4469
50/50	33.0	3155	678.0	1.5074

**Table 11. Pressure data of *B-KNO<sub>3</sub>/RDX* and *B-KNO<sub>3</sub>/HMX* compositions**

Wt (%)	Pressure (MPa)			Time to $P_{max}$ (ms)		$(dP/dt)_{max}$ (MPa/ms)		Time to $(dP/dt)_{max}$ (ms)	
	<i>B-KNO<sub>3</sub>/RDX</i>	<i>B-KNO<sub>3</sub>/HMX</i>	Predicted	<i>B-KNO<sub>3</sub>/RDX</i>	<i>B-KNO<sub>3</sub>/HMX</i>	<i>B-KNO<sub>3</sub>/RDX</i>	<i>B-KNO<sub>3</sub>/HMX</i>	<i>B-KNO<sub>3</sub>/RDX</i>	<i>B-KNO<sub>3</sub>/HMX</i>
100/0	2.9	2.9	2.6	7.0	7.0	0.8	0.8	1.9	1.9
90/10	3.4	3.4	3.2	6.2	4.0	1.3	2.6	1.9	0.7
80/20	4.1	3.9	3.9	5.2	4.0	1.6	3.0	1.3	0.7
70/30	4.6	4.5	4.6	5.4	3.8	1.7	4.0	1.1	0.7
60/40	5.3	5.2	5.4	5.2	3.8	2.2	4.3	1.1	0.7
50/50	5.8	5.7	6.2	5.0	3.6	3.4	6.1	0.7	0.3

**Table 12. Friction and impact sensitivities of *B-KNO<sub>3</sub>/RDX* and *B-KNO<sub>3</sub>/HMX* compositions**

Wt %	Friction sensitivity (kg force)				Impact sensitivity* (kg cm)			
	<i>B-KNO<sub>3</sub>/RDX</i>		<i>B-KNO<sub>3</sub>/HMX</i>		<i>B-KNO<sub>3</sub>/RDX</i>		<i>B-KNO<sub>3</sub>/HMX</i>	
	0 %	100 %	0 %	100 %	0 %	100 %	0 %	100 %
100/0	> 36	-	> 36	-	12	16	12	16
90/10	>36	-	32.4	36	10	14	10	12
80/20	32.4	36	28.8	32.4	10	12	8	12
70/30	21.6	24	21.6	25.2	8	12	8	12
60/40	12.8	14.4	12.8	14.4	8	10	8	10
50/50	12.8	14.4	12.8	14.4	8	10	8	10
RDX	12.8	14.4	-	-	-	-	-	-
HMX	12.8	14.4	-	-	-	-	-	-

\* Drop Weight 2 Kg

products of RDX and HMX interferes with the reaction between *B* and *KNO<sub>3</sub>* and catalyses it. Thus, the ignition temperature of *B-KNO<sub>3</sub>* charge is brought down. The products of reaction between *B* and *KNO<sub>3</sub>* are *BN(s)*, *B<sub>2</sub>O<sub>3</sub>*, *B(l)*, *BO*, *B<sub>2</sub>O<sub>2</sub>*, *KBO<sub>2</sub>*, etc. On addition of nitramine explosives like RDX and HMX, the amount of solid and liquid products decrease while the gaseous products increase. The flame temperature, gaseous volume, and pressure output increase, whereas the ignition delay is reduced. The average molecular weight of products also decreases. The heat output of *B-KNO<sub>3</sub>* composition is not affected by the addition of RDX/HMX. Friction and impact sensitivity values of *B-KNO<sub>3</sub>* decrease with the addition of explosive but lies within the safety limit. Thus, it can be concluded that addition of RDX/HMX improves the ignition characteristics of *B-KNO<sub>3</sub>* without sacrificing the heat output.

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