

Top Level Functionality of a Grenade

Abstract

This report provides a top-level functionality of a grenade and the explosive train. Investigating the reaction and energy released during each stage of the explosive train. In addition to discussing how energetic materials are manufactured.

It is found that while the theoretical energy released, and products created from reactions can be calculated. This does not reflect the physical reaction that occurs in the grenade. This is due to impurities, and the possibility of incomplete combustion.

Further research should be made into green explosives, which remove the use of toxic oxidisers that can leave long lasting effect on the environment or personnel.

Author: Frazer Graham

Module: ACDA4011

Company: Dstl

Table of Contents

Abstract.....	0
Introduction	2
Method	2
Research method:.....	2
The Explosive Train:	3
Energetic Materials used in the explosive train:.....	4
Thermochemistry:.....	4
Activation Energy	5
Results.....	6
Lead Styphnate – Compound:.....	6
Black Powder – Mixture	7
Potassium Nitrate – Compound.....	7
Sulphur – Element.....	8
Carbon – Element	8
Lead Azide	10
2-4-6 Trinitrotoluene	11
Crystal Structure Diagram:.....	12
Thermochemistry Results	13
Lead Azide	13
Lead Styphnate	13
Black Powder.....	13
Trinitrotoluene.....	13
Discussion.....	14
Conclusion.....	16

Introduction

There are several types of grenades each with their own function:

- High Explosive Fragmentation Grenade – To injure/kill targeted personnel.
- Smoke Screening Grenades – create cover or signal
- Stun Grenades - temporarily distort and disable targets
- Riot Control Grenade – control and disperse crowds

The objective of this report is to create a report describing a top-down functionality on a high explosive fragmentation grenade, such as a mill bomb. Focus will be made into how the explosive train operates to achieve the desired function of a high explosive's grenade. Additionally, energetic materials from each of the explosive train will be chosen for further investigation.

Such as the reaction during the ignition of the explosive train, energy released in each part and finally how the energetic materials are manufactured.

HAND GRENADE NO.5 (MILLS)

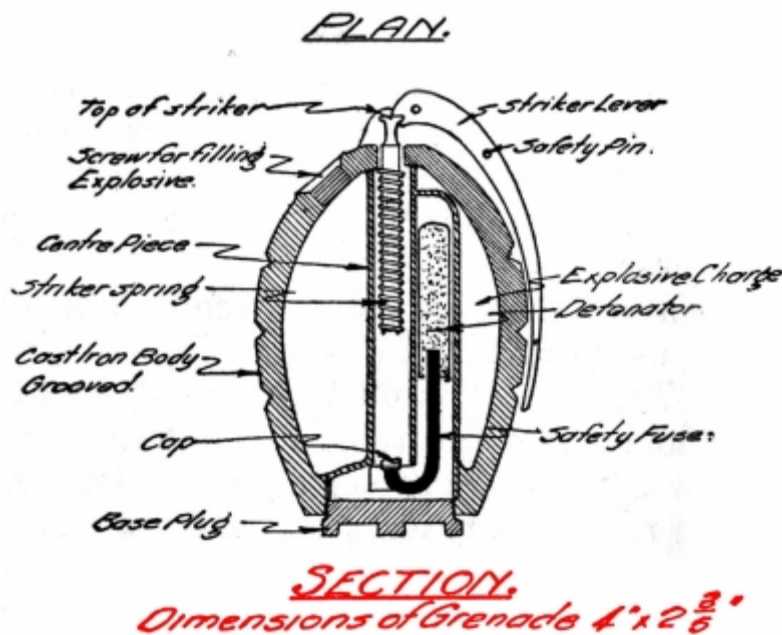


Figure No.1

Method

Research method:

Due to the restricted knowledge on the internet about grenades, chemical compositions, and manufacturing techniques. A wide range of sources will be used.

Research will be targeted at grenades used in world war one and world war two. This should result in more publicly available information from history websites.

Data will be collected from journals, databases, books, patents, and publicly available military documents/reports. To ensure reputable sources, preventing discrepancies in information.

The Explosive Train:

Throughout the grenade a variety of explosives are used to produce different effects and achieve different functions. This is known as the explosive train.

- Primers function is to receive a stimulus and ignite the delay composition. Therefore, it needs to be sensitive, but not too much in case of accidental stimulus, and provide a large amount of energy.
- Delay Composition functions are to receive ignition from the primer and to provide time delay effect before igniting the detonator. Therefore, it needs to burn at subsonic speeds and not detonate when confined. Preventing the chance of a runaway reaction.
- Detonators functions are to receive ignition from the delay composition and provide stimulus to the main charge to cause detonation. This should be less sensitive than a primer however still provides a large amount of energy at supersonic speeds.
- Main Charges functions is to provide main effect, which is blast and fragmentation. Therefore, it needs a high velocity of detonation and brisance to break the casing of the grenade and to throw fragmentation at great speeds.

An explosive train is a chain of explosives which produce energy to reach the activation energy level requirements of the next explosive within the chain. This will cause the next explosive within the chain to react and produce energy to achieve its desired function.

Two main features of the explosive train are:

1. Sensitivity decreases, as more energy is required to reach activation levels.
2. Energy output increases from each explosive

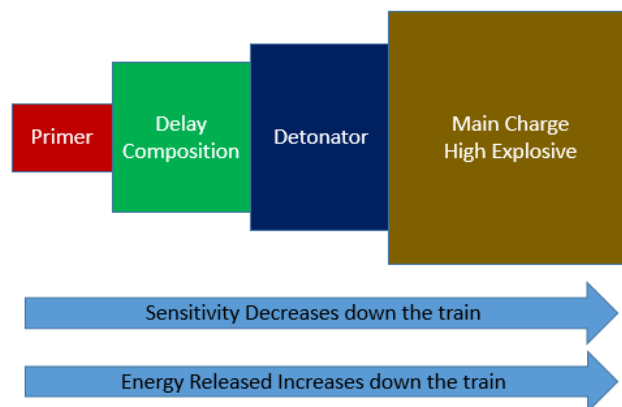


Figure No.2

Within each part of the explosive train a mixture of energetic materials are used. This is to combine physical and chemical characteristics. An example is for percussion caps lead styphnate is used with aluminium and lead azide. Aluminium acts as an oxidiser and increases the intensity of the heat produced. Lead azide mixed with lead styphnate increases overall sensitivity to shock.

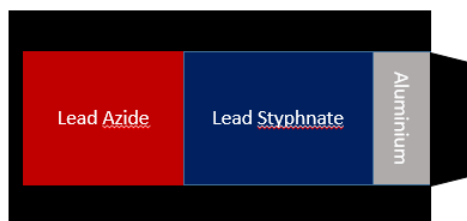


Figure No. 4

Energetic Materials used in the explosive train:

	Primers	Delay Compositions	Detonators	High Explosives
Energetic Material	Lead Styphnate	Black Powder	Lead Azide	TNT
	Tetrazene	Safety Fuze	Tetryl	PETN
	Picric Acid	Tungsten Delay	Silver Azide	C4
	Potassium Picrate	Zirconium-Nickel delay	Mercury Fulminate	RDX
	Nitrogen Triiodide	Black-match	KDNBF	HMX

Table No.1

Lead Styphnate, Black powder, lead azide and TNT will be further investigated for this report. To concentrate research efforts and reduce time collecting and reporting information.

Thermochemistry:

Explosives are chemical compounds/mixtures that have a large amount of potential energy. This energy is released and captured during the breaking of bonds from the reactants and the forming of bonds in the products.

To measure the energy released Enthalpy (Equation No.1) can be used to measure the energy of the bonds breaking and forming.

$$H = E + PV$$

Equation No.1

The energy of the system can be expanded to the heat of the system and work done by the system (Equation No.2).

$$\Delta H = q + w + \Delta(PV)$$

Equation No.2

If it is assumed that all reactions are happening at constant pressure, then only the change in volume effects the equation. (Equation No.3)

$$\Delta H = q + w + P\Delta V$$

Equation No.3

If the reaction causes an increase in pressure, there would be work done to the volume of the system. This would lead to a loss of internal energy. Therefore, Equation No.3 can be written as Equation No.4.

$$\Delta H = q - P\Delta V + P\Delta V$$

Equation No.4

Simplifying terms, the equation received is:

$$\Delta H = q$$

Equation No.5

Therefore, the change in energy can be expressed as Equation No.6.

$$Q = \Delta H_{(Reaction)} = \Sigma \Delta H_{f(products)} - \Sigma \Delta H_{f(explosive\ components)}$$

Equation No.6

If energy is positive, this shows that the compound is an endothermic reaction. Meaning, the reaction absorbs energy from its surroundings. While an exothermic reaction, energy is given to its surroundings. Therefore, for an explosive reaction all explosive reactions must be exothermic.

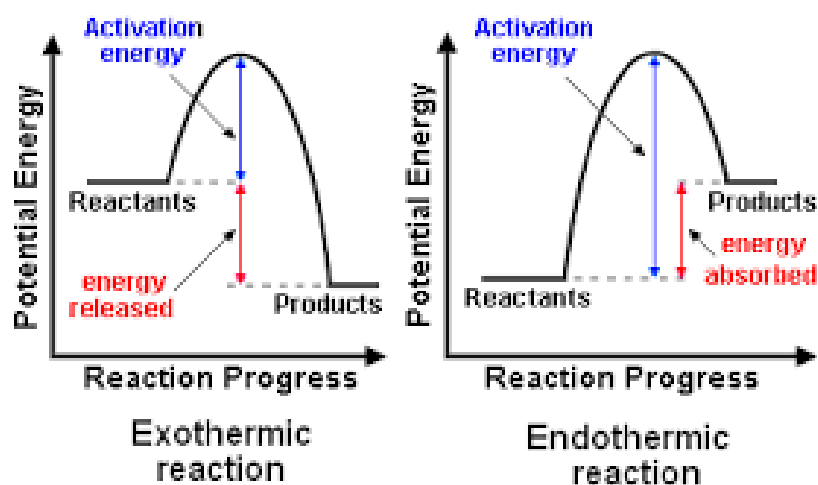


Figure No.5

Activation Energy

Before a reaction takes place, energy is required to start the reaction. This is known as activation energy. This can be calculated through Arrhenius equation.

$$K = Ae^{\frac{-E_a}{RT}}$$

Equation No.7

K is the rate constant; A is the frequency factor which includes the frequency and orientation of collisions for the reaction. While R is gas constant and T is temperature, while $-E_a$ is the activation energy.

This equation can be used to calculate the theoretical activation energy required for a reaction to start. This equation also shows the importance of how at higher temperatures less energy is required to reach the activation energy.

Results

Lead Styphnate:

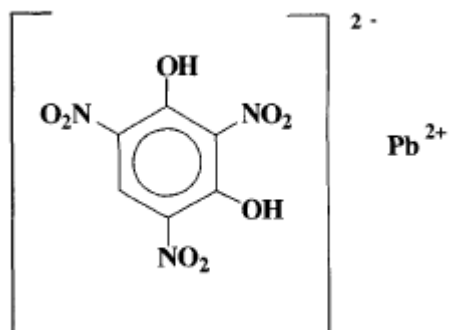
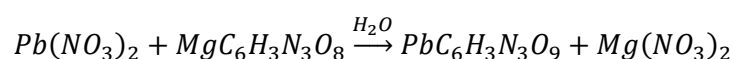


Figure No.6 and 7

Name:	Lead Styphnate	Formula:	$C_6H_3N_3O_9Pb$
Molecular Weight	468.3	Boiling Point	268 Celsius
Appearance	Orange yellow to dark brown Crystalline Solid	Melting Point	235 Celsius
Crystal Structure	a-form orthorhombic b-form monoclinic	Heat of Formation	-855Kj/mol
Oxygen Balance	-18.8%	Detonation Velocity	5200m/s
Nitrogen Content	8.97%	Impact Sensitivity	2.5 – 5 Nm
Odour	None	Solubility	500 mg/L
FOI	15	Power Index	21%

Manufacture

Lead styphnate is manufactured through the reaction of lead nitrate or acetate in a hot aqueous solution with acidified magnesium styphnate. To retrieve the lead styphnate, it is precipitated as a monohydrate.



If no admixtures are used, lead styphnate can easily explode through an electrostatic charge. Due to the static sensitivity of the lead styphnate manufacture should be made it relative humidity with adequate earthing and anti-static regimes should be enforced.

Attempts have been made to use graphite but are still considered dangerous. Other control factors are during the reaction, heat, concentration, and pH range needs to be monitored and controlled throughout the reaction. Additionally, by stirring this will improve the collision rate.

Shelf Life

Lead Styphnate when dry is extremely sensitive to static electricity and can cake. Trying to break up the cake is very hazardous as this could lead to detonation.

Moisture absorbed from the atmosphere can cause a slow chemical decomposition of principle ingredient leading to reduced efficiency or even failure.

Therefore, lead styphnate should be stored in a tightly closed container at all times, and kept in a cool, dry, well ventilated area. It should also be stored away from heat, sparks, flame and other sources of ignition and has a shelf life of two years. It is stable in storage, even at elevated temperature.

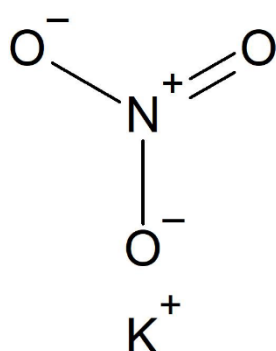
Black Powder**Potassium Nitrate**

Figure No. 8 and 9

Name:	Potassium Nitrate	Formula:	KNO_3
Molecular Weight	101.1	Boiling Point	400 Celsius
Appearance	Colourless – greyish Crystals Solid	Melting Point	314 Celsius
Crystal Structure	Orthorhombic Crystal Trigonal Crystal	Heat of Formation	-494.48Kj/mol
Oxygen Balance	+39.6%	Combustion Rate	120m/s
Nitrogen Content	13.86%	Impact Sensitivity	15Nm
Odour	None	Solubility	383000 mg/L

Sulphur

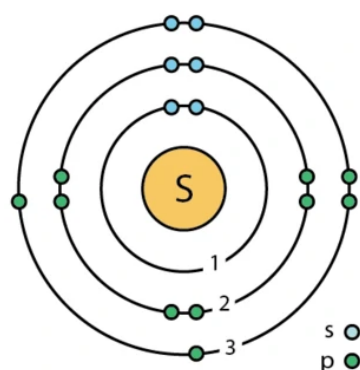


Figure No. 10 and 11

Name:	Sulphur	Element Symbol:	S
Molecular Weight	32	Boiling Point	444.61 Celsius
Appearance	Yellow Solid	Melting Point	115.21 Celsius
Crystal structure	Orthorhombic	Oxidation States	-2 Sulfide, +4 Sulfite +6 Sulfate
Electron Configuration	$[Ne]3s^23p^4$	Allotrope	Yes

Carbon

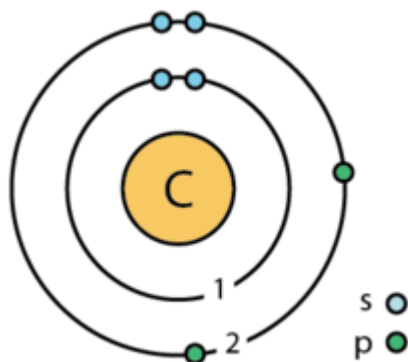


Figure No. 12 and 13

Name:	Charcoal (Carbon)	Element Symbol:	C
Molecular Weight	12	Boiling Point	Sublimes at 3825 Celsius
Appearance	Black Solid	Melting Point	Sublimes at 3825 Celsius
Crystal structure	Hexagonal	Oxidation States	-4, +4
Electron Configuration	$[He]2s^22p^2$	Polymorph	Yes

Manufacture of Gunpowder

For a fuze the composition would be 75% potassium nitrate, 10% Sulphur and 15% charcoal, and its grain size would be 0.25mm – 0.75mm. This is because if the grain is too fine, then the burn rate would increase due to a greater surface area to combust. However, if the grain size is too large then this could prevent ignition to other grains from the lack of energy.

To manufacture, the components are finely ground to the appropriate size and then mixed and compacted in rolling mills. The mixture is then pressed in with a hydraulic press into cakes. These cakes can then be broken and sieved for certain grain sizes. The grain required would be selected and sieved out from the batch. Graphite can be added to help de-sensitize it from electrostatic charges. The broken granules can then be free poured into bores.

This mixture may be placed with cotton to help the burn throughout the fuze.

To manufacture potassium nitrate for the mixture, it can be manufactured by using two aqueous solutions of sodium nitrate and potassium chloride. This will create a double displacement between the nitrate and chloride. Using precipitation to remove the potassium nitrate from the solution.

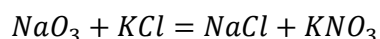


Figure No.14

Shelf Life

Black powder under the correct storage conditions does not degrade nor does its sensitivity increase or decrease even at 120 Celsius. After ageing black powder has limited effect of its explosive power.

However, if moisture is absorbed from the air, as black powder is hygroscopic it can lead to firing difficulties and burning difficulties. Therefore, it is best to keep black powder away from moisture.

Lead Azide

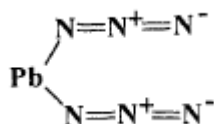


Figure No. 15 and 16

Name:	Lead Azide	Formula:	PbN_6
Molecular Weight	291.3	Boiling Point	260 Celsius
Appearance	Colourless to white crystalline Solid	Melting Point	190 Celsius
Crystal Structure	a-form orthorhombic b-form monoclinic	Heat of Formation	+469 KJ/mol
Oxygen Balance	-5.5%	Detonation Velocity	4500-5300m/s
Nitrogen Content	28.85%	Impact Sensitivity	2.5 – 4 N.m
Volume of explosion gases	231 L/kg	Solubility	230 mg/L
Friction Sensitivity	0.1N	Allotrope	Yes
FOI	30	Power Index	13%
Manufacture Azides are salts of hydrazoic acids. It can be manufactured from the reaction between lead nitrate and sodium azide in an aqueous solution in basic conditions. $Pb(NO_3)_2 + 2NaN_3 = Pb(N_3)_2 + 2NaNO_3$ However, during manufacturing care must be taken to avoid large crystals forming. Crystals of 1mm in length are subject to spontaneous explosion. Crystals should be no longer that 0.1mm. If these crystal break detonations can occur. Dextrin and sodium carboxymethylcellulose is usually added to help control and prevent crystal growth in addition the alpha form of the crystal can be prepared with rapid stirring of the solution. While the B-form is created by slowly diffusing the solutions together.			
Shelf Life Crystallised azide can be stored under water with dextrin for a long period of time, however crystal size can grow due to it being hygroscopic. If the azide is dry (not wetted) and exposed to moisture it can corrode with copper and zinc creating other azides. Therefore, it should not be stored with uncoated copper or alloys of copper. If exposed to moisture when dried it can slowly decompose the principal ingredient leading to reduced efficiency or even failure			

2-4-6 Trinitrotoluene

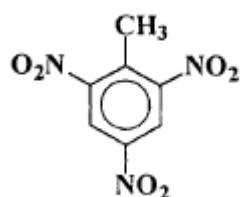


Figure No. 17 and 18

Name:	Tri-nitro-toluene	Formula:	$C_7H_5N_3O_6$
Molecular Weight	468.3	Boiling Point	300 Celsius
Appearance	Pale yellow Crystalline Solid	Melting Point	80.8 Celsius
Crystal Structure	Five Isomers 2-4-6-Trinitrotoluene	Heat of Formation	-26Kj/mol
Oxygen Balance	-73.9%	Detonation Velocity Confined	6900m/s
Nitrogen Content	18.5%	Impact Sensitivity	15Nm
Electrostatic Discharge	4.5J	Solubility	130 mg/L
Detonation Pressure	19.00Gpa (Calculated)	Isomer	Yes
FOI	150	Power Index	115%

Manufacture

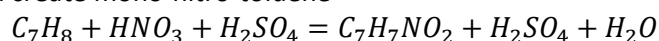
For military applications only the 2,4,6 isomer can be used. This is done by recrystallization in benzene or 62% nitric acid.

Only two isomers can produce 2,4,6-nitrotoluene which are ortho-and para isomers.

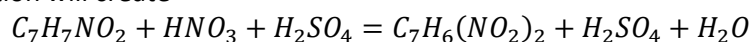
The isomers not wanted can be removed/destroyed using sodium sulphite aqueous solution or at each stage the unwanted isomers can be separated by distillation or freezing out in the mononitrate stage.

To manufacture TNT toluene needs to be nitrated three times, with mixed acids with free SO_3 .

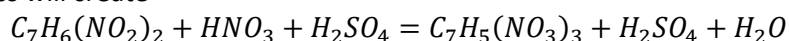
The first nitration will create mono-nitro-toluene



The second nitration will create



The third process will create



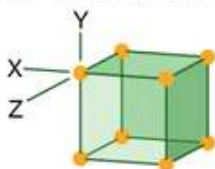
Each time toluene has been nitrated, temperature needs to increase for the next nitration to occur. This could lead to an explosion if not monitored correctly.

Shelf Life

During ageing the detonation velocity gradually decreases while the sensitivity increase. The volume of TNT also increases due to thermal expansion. This could lead to cracking which could cause hot spots or uneven detonation. Furthermore, can cause the breaking of the case if TNT is bonded to it. TNT can also exude.

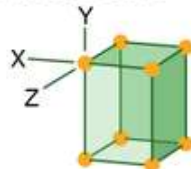
Crystal Structure Diagram:

The seven primitive crystal systems



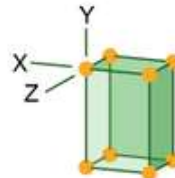
Isometric (or cubic)

All three axes are equal in length, and all are perpendicular to one another.



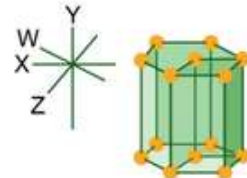
Tetragonal

Two of the three axes are equal in length, and all three axes are perpendicular to one another.



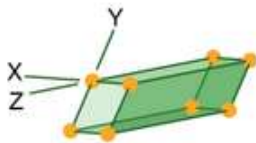
Orthorhombic

All three axes are unequal in length, and all are perpendicular to one another.



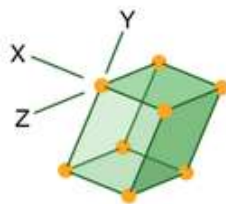
Hexagonal

Of four axes, three are of equal length, are separated by equal angles, and lie in the same plane. The fourth axis is perpendicular to the plane of the other three axes. Hexagonal cells have lattice points in each of the two six-sided faces.



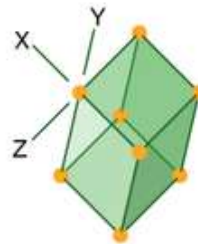
Triclinic

All three axes are unequal in length, and none is perpendicular to another.



Monoclinic

All three axes are unequal in length, and two axes are perpendicular to each other.



Rhombohedral (or trigonal)*

All three axes are of equal length, and none of the axes is perpendicular to another, but the crystal faces all have the same size and shape.

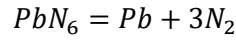
Figure No 19

Thermochemistry Results

$$\Sigma \Delta H_{f(\text{products})} - \Sigma \Delta H_{f(\text{explosive components})} = \Delta H_{(\text{Reaction})} = Q$$

Equation No.8

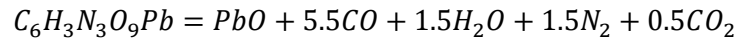
Lead Azide



$$[0 + 0] - [(+469)] = -469 \frac{kJ}{mol}$$

Equation No.9

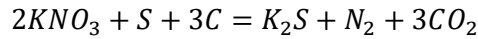
Lead Styphnate



$$[-217.9 + (5.5 \cdot -110.5) + (1.5 \cdot -285.8) + 0 + (0.5 \cdot -393.5)] - [(-885)] =$$
$$-1385.1 - (-855) = -530.1 \frac{kJ}{mol}$$

Equation No.10

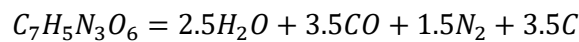
Black Powder



$$[(-380) + 0 + (3 \cdot -393.5)] - [(2 \cdot -494.48)] =$$
$$-1560.5 - (-988.96) = -571.54 \frac{kJ}{mol}$$

Equation No.11

Trinitrotoluene



$$[(2.5 \cdot -241.8) + (3.5 \cdot -110.5) + 0 + 0] - [(-26)] =$$
$$-991.25 - (-26) = -965.25 \frac{kJ}{mol}$$

Equation No.12

Compound	Heat of Formation (Kj/mol)
Lead Styphnate	-855(Kj/mol)
Potassium Nitrate	-494.48 Kj/mol
Lead Azide	+469 (Kj/mol)
Trinitrotoluene	-26(Kj/mol)
Hydrogen Oxide	-241.8 (kj/mol)
Carbon Monoxide	-110.5 (Kj/mol)
Carbon Dioxide	-393.5(Kj/mol)
Lead Oxide	-217.9(kj/mol)
Potassium Sulfide	-380(Kj/mol)

Table No.2

Discussion

From the change in energy results, it can be seen that energy released increased at each part of the train. However, this statement does not consider the fact there are two moles of black powder, compared to the singular moles of lead azide, lead styphnate and Trinitrotoluene.

Lead Styphnate, and TNT produce more energy from their reactions due to having more intimate bonds between their fuels and oxidisers. Both TNT and lead styphnate have an aromatic structure consisting of sigma bonds and pi bonds. As a result of these bonds, more energy is released when they are broken. Additional, by having oxygen and nitrogen with the oxidiser in the molecules they can create self-sustaining reactions.

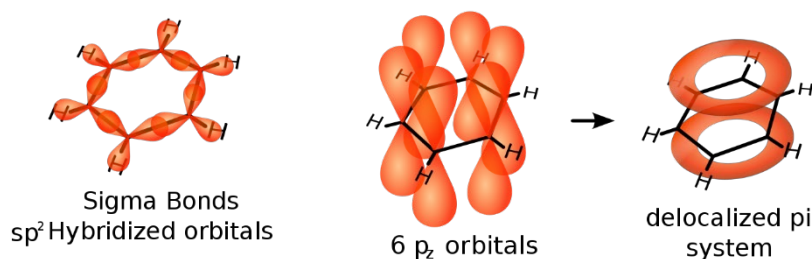


Figure No.20

The disadvantages of an energetic mixture are that there are no chemical bonds between the fuels and oxidiser. By improving the intimacy between the two this will increase the rate the reaction and possible lead to a run-away reaction from the heat produced. Therefore, black powder is manufactured into fine granules to increase the surface area and intimacy between the fuel and oxidiser to increase the rate of reaction.

However, a runaway reaction is not ideal for a time delay composition. Therefore, black powder should not be used. Especially since it can detonate upon confinement. This could then prematurely function the grenade, injuring friendly personnel.



Figure No.20

All results calculated show an exothermic reaction due to being a negative value. This shows that energy is being released to the surroundings. However, these calculations do not factor impurities.

Dirt or foreign objects during the manufacturing/processing phase may get caught and trapped. This would reduce the overall effectiveness of the explosive.

Incomplete combustion also effects the overall effectiveness. Explosive like TNT could be improved by improving its oxygen balance. Due to the oxygen balance of TNT, it does not have enough oxygen molecules to produce carbon dioxide. Instead, carbon monoxide is created. By reducing the oxygen balance to zero, more energy will be released.

Incomplete Combustion

$$C_7H_5N_3O_6 = 2.5H_2O + 3.5CO + 1.5N_2 + 3.5C$$

$$[(2.5 \cdot -241.8) + (3.5 \cdot -110.5) + 0 + 0] - [(-26)] =$$

$$-991.25 - (-26) = -965.25Kj$$

Equation No.13

Complete Combustion

$$C_7H_5N_3O_6 = 2.5H_2O + 7CO_2 + 1.5N_2$$

$$[(2.5 \cdot -241.8) + (7 \cdot -393.5) + 0] - [(-26)] =$$

$$[(2.5 \cdot -241.8) + (7 \cdot -393.5) + 0] - [(-26)] = 2124Kj$$

Equation No.14

While TNT does not fully combust, it does have a high velocity of detonation and low sensitivity. If mixed with an oxygen rich high explosive this could achieve a greater overall effect. Especially since TNT does not have a great brisance effect when compared to other high explosives. Although, it is cheap to manufacture and easy to pour. Therefore, being an excellent economical choice.

The disadvantages of using lead styphnate and lead azide is that it is highly toxic due to the lead used. This could damage the environment and over time poison operators. However, the benefits are that they are reliable and well documented. Lead azide and lead styphnate have been used since world war 2.

Conclusion

- All energetic materials showed an exothermic result with TNT and Lead styphnate producing the most energy because of their closely bonded fuel, and oxidizers atoms and many bonds.
- The oxygen balance effects overall performance of an explosive. If balanced, explosive can provide more energy due to complete combustion. Therefore, a mixture of oxygen rich and fuel rich explosive should be used to improve the overall effect.
- Research should be made to find non-toxic alternatives for the primary explosive and detonator, to prevent long lasting damage on the environment and personnel.
- Finally, black powder should not be used as a time delay composition due to the fact under confinement a runaway reaction can occur leading to premature detonation.

References

Bibliography