

Top Level Functionality of a Grenade

Abstract

This report provides a top-level functionality of a grenade and explosive train. Investigating reactions, manufacturing methods and energy released during each stage of the explosive train.

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

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Introduction

There are several types of grenades each with their own function [1]:

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

The objective of this report is to describe a top-down functionality on a high explosive fragmentation grenade (Figure No.1). Research will be made into how the explosive train operates to achieve desired function. Additionally, four energetic materials (Lead Styphnate, Black Powder, Lead Azide, Trinitrotoluene) from the explosive train will be chosen for further investigation.

Such as the reaction products, energy released and how the energetic materials are manufactured.

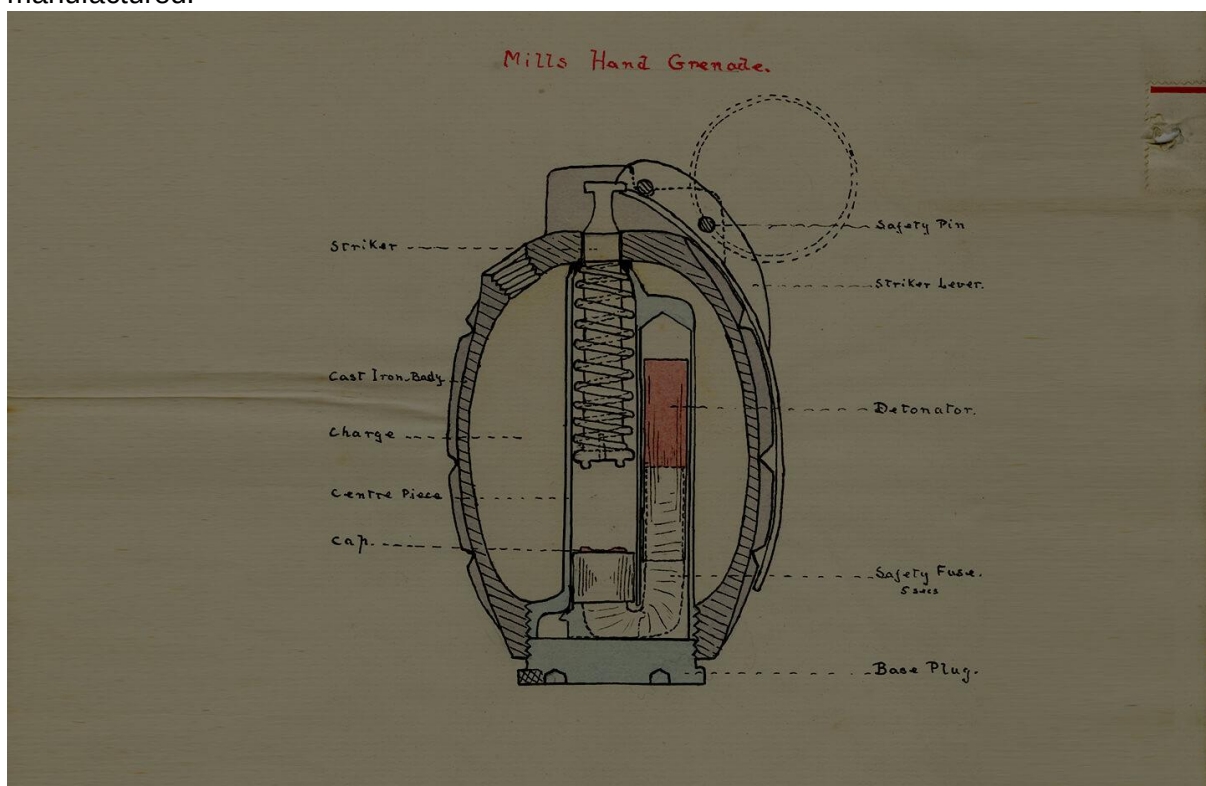


Figure No.1 – Mills Bomb [2]

Method

Research method:

Knowledge about explosives, manufacturing method and explosive data is limited on the internet. Therefore, 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. To ensure reputable sources, preventing discrepancies in information.

Explosive Train:

Throughout the grenade 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. It needs to be sensitive, but not too much in case of accidental stimulus, and provide a large amount of energy. [3]
- Delay Composition functions are to receive ignition from the primer and to provide a time delay. It needs to burn at subsonic speeds and not detonate when confined. Preventing the chance of a runaway reaction. [3]
- 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 and undergo a deflagration to detonation transition. [3]
- Main Charges functions is to provide main effect (blast and fragmentation). It needs a high velocity of detonation and brisance to break the casing of the grenade and to throw fragmentation at great speeds. Desirably it should have a low sensitivity to accidental stimulus. [3]

An explosive train (Figure No.2) is a chain of explosives which produce energy to reach the activation energy level of the next explosive within the chain. This will cause the next explosive within the chain to react, to achieve its desired function. [4]

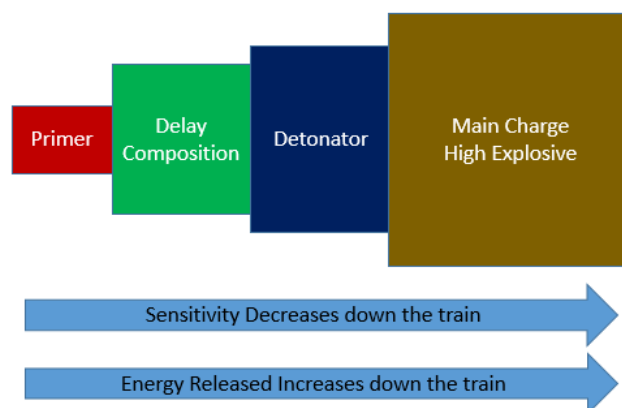


Figure No.2

Within each part of the explosive train mixtures of energetic materials is used to combine physical and chemical characteristics (Figure No.3). For percussion caps lead styphnate is mixed 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. [5]

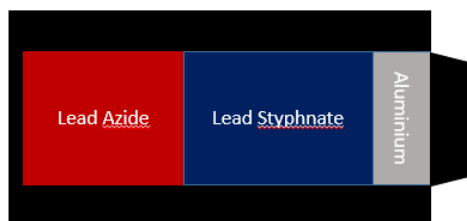


Figure No. 3

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 [3] [6] [4] [7] [8]

Thermochemistry:

Explosives are chemical compounds/mixtures that have a large amount of potential energy. [6] 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 [9]

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 [6]

If the energy released is positive, this is an endothermic reaction; The reaction absorbs energy from its surroundings.

An exothermic reaction, energy is given to its surroundings. Therefore, explosive reactions must be exothermic. (Figure No.5)

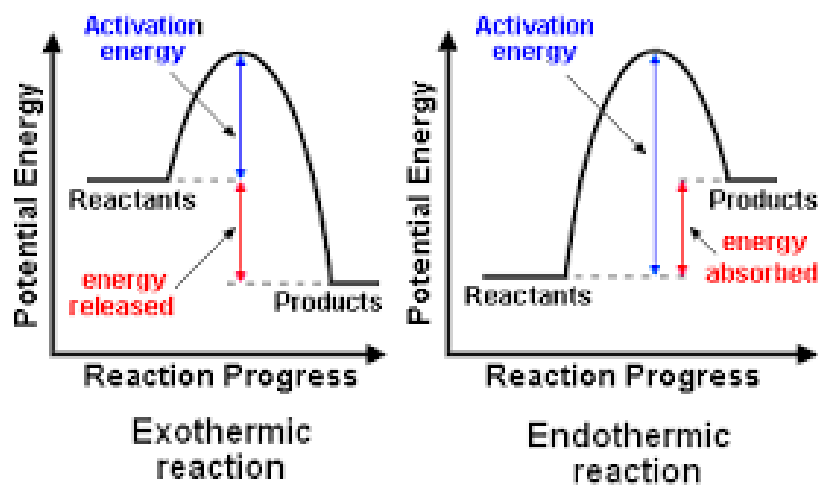


Figure No.4 [10]

Activation Energy

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

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

Equation No.7 [11]

K is the rate constant; A is the frequency factor (frequency and orientation of molecule collisions); R is gas constant; T is temperature; $-E_a$ is the activation energy.

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

Results

Lead Styphnate:

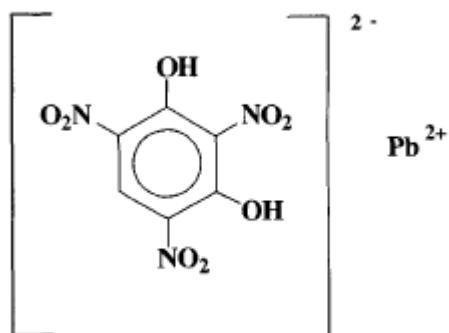


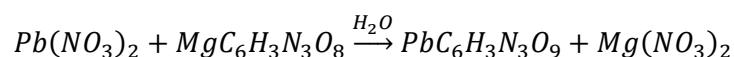
Figure No.5 and 6 [6] [12]

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 (LS) is manufactured through the reaction of lead nitrate/acetate in a hot aqueous solution with acidified magnesium styphnate.

Lead Styphnate is separated through precipitation as a monohydrate.



If no admixtures are used, it can easily explode through an electrostatic charge. Due to the static sensitivity of the LS, it should be manufactured in a relative humidity with adequate earthing and antistatic regimes.

Attempts have been made to use graphite to reduce static sensitivity 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. By stirring, this will increase the collision rate.

Shelf Life

LS when dry is extremely sensitive to static electricity and can cake. Breaking the cake is very hazardous as this could lead to detonation.

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

LS should be stored in a tightly closed container, and kept in a cool, dry, 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.

[13] [14] [15] [16] [3] [6]

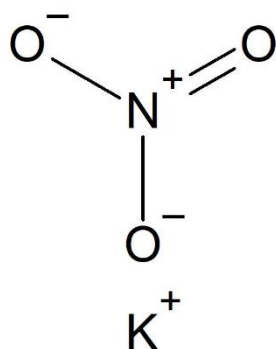
Black Powder**Potassium Nitrate**

Figure No. 7 and 8 [17] [18]

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

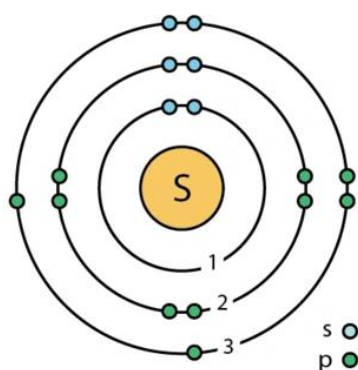


Figure No. 9 and 10 [19] [20]

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

[21]

Carbon

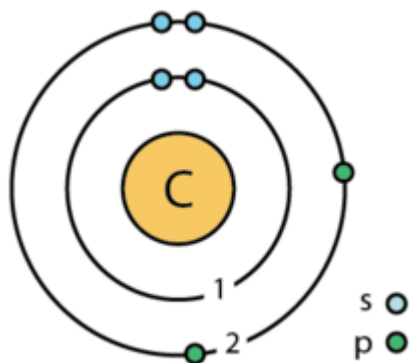


Figure No. 11 and 12 [22] [23]

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

[24]

Manufacture of Gunpowder

For a fuze, the composition would be 75% potassium nitrate, 10% Sulphur and 15% charcoal; [4] its grain size would be 0.25mm – 0.75mm, 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 will cause a delayed reaction and may not achieve its desired function.

To manufacture, the components are finely grounded to the appropriate size and then mixed and compacted in rolling mills. It is then pressed in with a hydraulic press into cakes. These cakes can then be broken and sieved for certain grain sizes. Graphite can be added to help de-sensitive it from electrostatic charges. The broken granules can then be free poured into bores. [6] [3] [4]

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.

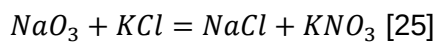


Figure No.13

[26]

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. [27] [28]

However, if moisture is absorbed from the air, as black powder is hygroscopic it can lead to firing difficulties and burning difficulties. Therefore, keep black powder away from moisture. [29]

Lead Azide (LA)

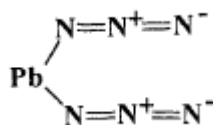
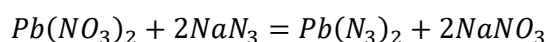


Figure No. 14 and 15 [6] [30]

Name:	Lead Azide (LA)	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.



However, care must be taken to avoid large crystals forming. Crystals of 1mm in length are subject to spontaneous explosion. Crystals should be no longer than 0.1mm. If crystal break detonations can occur. Dextrin and sodium carboxymethylcellulose are added to help control and prevent crystal growth.

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 and exposed to moisture it can corrode with copper and zinc creating other azides.

It should not be stored with uncoated copper or alloys of copper.

If exposed to moisture when dried it slowly decompose the principal ingredient leading to reduced efficiency or even failure

2-4-6 Trinitrotoluene

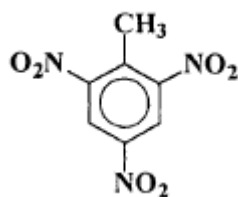


Figure No. 16 and 17 [6] [34]

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

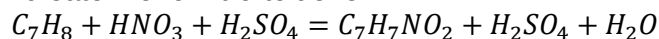
For military applications only the 2,4,6 isomer can be used. This is done by recrystallization in benzene or 62% nitric acid.

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

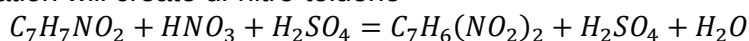
The unwanted isomer can be removed using sodium sulphite aqueous solution or at each stage the unwanted isomers can be separated by distillation or freezing out in the mononitrate stage.

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

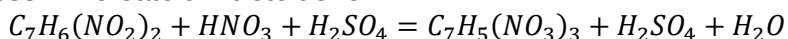
The first nitration will create mono-nitro-toluene



The second nitration will create di-nitro-toluene



The third process will create trinitrotoluene.



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

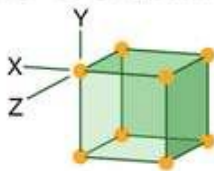
Shelf Life

During ageing the detonation velocity gradually decreases while 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.

[35] [36] [3] [6] [4]

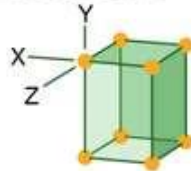
Crystal Structure Diagram:

The seven primitive crystal systems



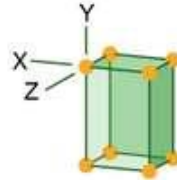
Isometric (or cubic)

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



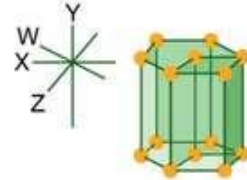
Tetragonal

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



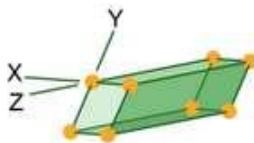
Orthorhombic

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



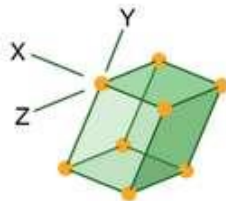
Hexagonal

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.



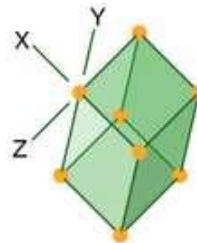
Triclinic

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)*

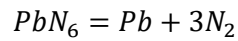
All three axes are of equal length, and none of the axes is perpendicular to another, but the crystal faces all have the same size and shape.

Thermochemistry Results

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

Equation No.8 [6]

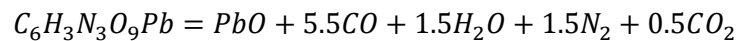
Lead Azide



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

Equation No.9

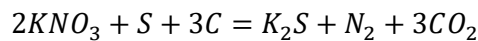
Lead Styphnate



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

Equation No.10

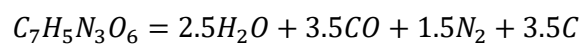
Black Powder



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

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 [38] [39]

Discussion

From the change in energy results, 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 (TNT).

Lead Styphnate, and TNT produce more energy from their reactions due to having more intimate bonds between their fuels and oxidisers. 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. Additionally, by having oxygen, nitrogen, and the oxidiser within the molecules they can create self-sustaining reactions. [40]

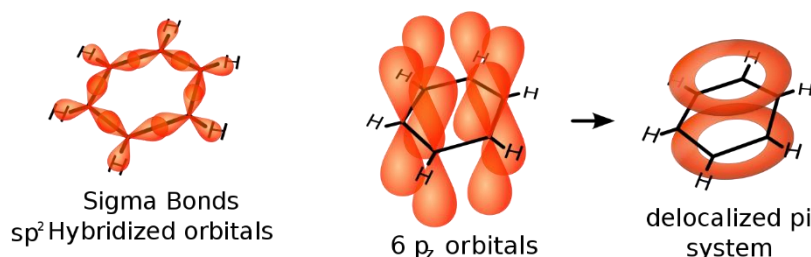


Figure No.19 [41]

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 possibly 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.



Figure No.20 [42]

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 prematurely function the grenade, injuring friendly personnel.

All results calculated show an exothermic reaction due to being a negative value. However, these calculations do not factor impurities. Dirt or foreign objects during the manufacturing phase may get caught and trapped. This would reduce the overall effectiveness of the explosive.

Incomplete combustion also effects overall effectiveness. Explosive like TNT could be improved by improving its oxygen balance. TNT does not have enough oxygen molecules to produce carbon dioxide. Instead, carbon monoxide is created. If more oxygen molecules were supplied, more energy could 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 TNT 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 being an excellent economical choice.

Lead Styphnate and Lead Azide are both toxic. As a result, 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.

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