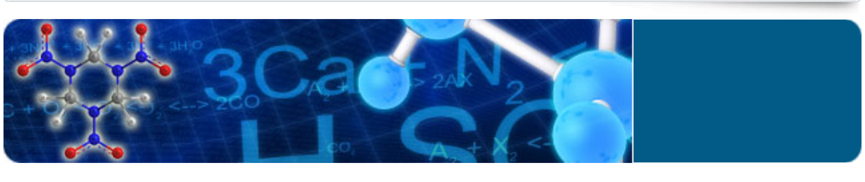


Articles - Liquid Explosives review

Introduction

Explosives may be classified according to a wide variety of parameters, some of which are related to their properties, while others – to the applications they serve. The classification is usually performed on the basis of one or more of the following characteristics:

- Chemical structure
- Chemical and physical properties: state, detonation speed, brisance (the shattering effect of a high explosive)
- The material's sensitivity to initiation (classification based on safety considerations)
- The explosives' civilian and military applications

This review will focus on the chemical and physical properties of liquid explosives (one explosive substance or more, when dealing with a mixture), and the main applications in which various liquid explosives are used.

Liquid Explosives

Liquid explosives may be classified into the following categories:

- Liquid
- Suspension
- Emulsion

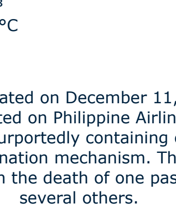
Explosives can be manufactured from either one or a number of substances. Liquid explosives, similarly to all other explosives, are found in a metastable state, enabling (under suitable conditions) the occurrence of a quick chemical reaction without requiring the presence of an environmental reactant, such as oxygen. Liquid explosives can be initiated through mechanical shock, friction or heat.

The Development of Liquid Explosives and their Use

Nitroglycerin

The first liquid explosive, nitroglycerin, was invented in 1846 by an Italian chemist named Ascanio Sobrero, who nitrated glycerin with a solution containing nitric acid and sulfuric acid. This substance, belonging to the nitro esters family, significantly expanded the range of applications in which explosives could be used, to include new applications previously served only by black gunpowder.

The safe manufacture and transport of nitroglycerin was problematic; over the years, it took the lives of many. When transporting nitroglycerin, small bubbles are created, which are then compressed when the substance is in motion. This compression results in a local, momentary rise in temperature and pressure, causing a detonation even when the motion is slight.
Many potential ways of overcoming this problem were examined before a solution was found in 1860 by Alfred Nobel: mixing nitroglycerin with a solid substance, which absorbs it. This mixture, which contains nitroglycerin and a Kaisel Gohr-type clay, is called dynamite.



Nitroglycerin chemical structure

Characteristics:

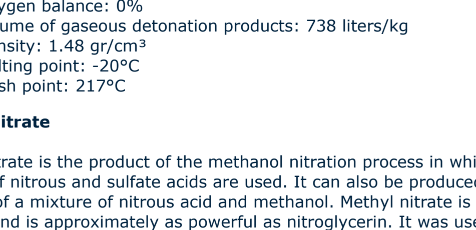
- Appearance: an oily, clear liquid, often yellowish
- Molecular formula: $C_3H_5N_3O_9$
- Molecular weight: 227.1 gr/mol
- Oxygen balance: +3.5%
- Volume of gaseous detonation products: 716 liters/kg
- Density: 1.59 gr/cm³
- Melting point: +13.2°C

In a terror attack perpetrated on December 11, 1994, a bomb made of nitroglycerin was planted on Philippine Airlines flight 434. It was concealed in a bottle purportedly containing contact lens cleaning solution, with a delay detonation mechanism. The blast caused a rupture in the fuselage, resulting in the death of one passenger and the injury of several others.

Additional Commonly Used Liquid Explosives

Nitroglycol

The explosive properties of Nitroglycol (also known as ethyleneglycol dinitrate - EGDN) are similar to those of nitroglycerin; however it is more than 100 times more volatile than nitroglycerin, and is 4 times as soluble. Since nitroglycol's vapor pressure is much higher than nitroglycerin's, it can serve a relatively limited number of applications. It is less viscous than nitroglycerin, and can accelerate the speed of nitrocellulose-based gelatin preparation processes. Mixing nitroglycol together with nitroglycerin in various dynamites enables using the dynamite-based explosives in cold climate countries, at low temperatures in which nitroglycerin freezes and is unsafe. Similarly to other nitro esters, nitroglycol also affects blood circulation; consequently, exposure to it is unsafe unless its concentration is low



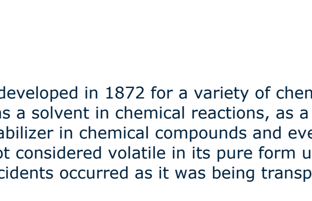
Chemical structure of a nitroglycol molecule

Characteristics:

- Appearance: an oily, clear liquid, often yellowish
- Molecular formula: $C_2H_4N_2O_6$
- Molecular weight: 152.1 gr/mol
- Oxygen balance: 0%
- Volume of gaseous detonation products: 738 liters/kg
- Density: 1.48 gr/cm³
- Melting point: -20°C
- Flash point: 217°C

Methyl Nitrate

Methyl nitrate is the product of the methanol nitration process in which a mixture of nitrous and sulfate acids are used. It can also be produced by distilling of a mixture of nitrous acid and methanol. Methyl nitrate is volatile, and is approximately as powerful as nitroglycerin. It was used as a liquid propellant in the past, before being replaced with more stable, safer substances.



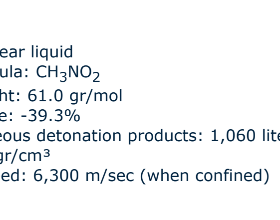
Chemical structure of a methyl nitrate molecule

Characteristics:

- Appearance: clear liquid
- Molecular formula: CH_3NO_3
- Molecular weight: 77.0 gr/mol
- Oxygen balance: -10.4%
- Volume of gaseous detonation products: 873 liters/kg
- Density: 1.22 gr/cm³

Nitromethane

Nitromethane was developed in 1872 for a variety of chemical uses, including to serve as a solvent in chemical reactions, as a component of detergents, as a stabilizer in chemical compounds and even as fuel for race cars. It was not considered volatile in its pure form until the 1950s, when numerous accidents occurred as it was being transported.



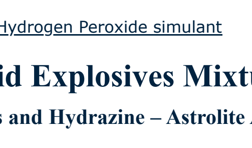
Chemical structure of a nitromethane molecule

Characteristics:

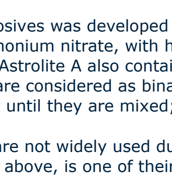
- Appearance: clear liquid
- Molecular formula: CH_3NO_2
- Molecular weight: 61.0 gr/mol
- Oxygen balance: -39.3%
- Volume of gaseous detonation products: 1,060 liters/kg
- Density: 1.14 gr/cm³
- Detonation speed: 6,300 m/sec (when confined)

Hydrogen Peroxide

Hydrogen peroxide is not used an explosive. In its pure form, and under certain conditions of confinement, it may detonate. Hydrogen peroxide is mainly used either as a pure liquid propellant which, when undergoing a catalytic process, breaks down into oxygen; or as an oxidant in a propellant mixture – when an organic fuel substance is added to it. It is only suitable for such purposes in concentrations that are significantly higher than those serving commercial and medicinal purposes.



Chemical structure of a hydrogen peroxide molecule



Hydrogen Peroxide simulant

Types of Liquid Explosives Mixtures

Mixtures of Oxidants and Hydrazine – Astrolite A and Astrolite G Explosives

The Astrolite family of explosives was developed in the 1960s by combining an oxidant: ammonium nitrate, with hydrazine: a fuel, at a stoichiometric ratio of 1:1. Astrolite A also contains about 20% aluminum powder. These substances are considered as binary materials, since both components are not brisant until they are mixed; this action can be performed even on site.
Astrolite A and Astrolite G are not widely used due to the high toxicity of hydrazine, which, as stated above, is one of their main components.
Characteristics:

- Appearance: clear liquid
- Molecular formula: $(NH_2)_2$ H_2O/NH_4NO_3
- Volume of gaseous detonation products: 1,112 liters/kg
- Density: 1.36 gr/cm³
- Detonation speed:
  - Astrolite A: 7,800 m/sec
  - Astrolite G: 8,600 m/sec

Mixtures of Hydrogen Peroxide and Organic Materials

Using hydrogen peroxide in mixtures, to act as an oxidant, with various organic materials, has led to the development of different types of explosives and propellants with a higher energy content than the energy resulting from the detonation of pure hydrogen peroxide. Examples of mixtures can be found in a variety of patents, in which hydrogen peroxide is mixed with, for example, flour, sawdust, water, glycerin, ammonium nitrate and more.
Examples of such mixtures include:

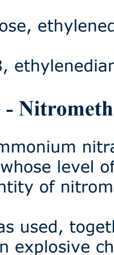
- Hydrogen peroxide at a concentration of 60%-90%, sawdust, resin and a gelling agent (starch or agar-agar).
- Low concentration hydrogen peroxide, glycerin and water.
- Hydrogen peroxide at low or high concentrations, hydrazine and water, to produce explosives rich in gaseous detonation products.
- Hydrogen peroxide, ammonium nitrate and water.

Nitromethane Mixtures

In 1945, an American named Ed Laurence succeeded to improve the explosive performance and chemical stability of nitromethane by combining it with chemical substances belonging to the amine family. Additional developments include combinations such as aluminum ammonium nitrate with various acids.
In principle, any amine can be used to prepare a nitromethane explosive; however, the best results are achieved when using aliphatic, and not aromatic amines. The recommended amines include ethylenediamine-morpholine, diethlaminoethanol; and Aniline and Tetraethylenepentamine.

PLX

PLX, which was used in the past for remote detonation of land mines, is produced by combining 95% nitromethane with 5% ethylenediamine. Additional amine derivatives have been tried; however, the above has been found to be the most effective ratio for an explosive substance.
In 1987, an explosive device combining C4 and PLX was used to blow up Korean Airlines flight 858. The device was carried onboard by North Korean agents.



PLX Explosive

Nitromethane-based Gelatines

These gelatins contain nitromethane, an amine derivative, a thickening substance and aluminum.
Examples of this type of mixtures include:

- Nitromethane, nitrocellulose, ethylenediamine and aluminum powder
- Nitromethane, Benton 38, ethylenediamine and aluminum powder

ANNM, Ammonium Nitrate - Nitromethane

Combining nitromethane and ammonium nitrate at a ratio of 60:40 creates a porridge-like mixture whose level of viscosity and moisture can be altered by changing the quantity of nitromethane that is added to the mixture.
In April 1995, this substance was used, together with diesel fuel additives, to prepare the 2.5-ton explosive charge used in the attack on the Alfred B. Murrah Federal Building in Oklahoma City.
A characteristic example of the composition of ANNM is nitro methane + ammonium nitrate + gelling agent (nitrocellulose, ethyl cellulose, cellulose acetate or polyoxyethylene).

Combinations of Nitric Acid and Organic Materials

Hellhoffites are one of the first families comprising liquid explosives that are mixed with dinitrobenzene or dinitrochlorobenzene and concentrated nitric acid. These mixtures were widely used mostly from 1880 till 1897; in later years their use was significantly reduced due to stability and safety problems. Dinitrobenzene was first synthesized by St. C. Deville in 1841 in a process that is similar to the manufacturing process of TNT (a reflex reaction of benzene with concentrated nitric acid). By changing the ratios of DNB isomers (orto, meta, para) and different compression parameters, mixtures with the desired viscosity and density were obtained. These are known as Boloron; they were in use in Austria after World War II.

The Hellhoffites are known in the USA under the name of dithekite; they contain different ratios of nitrobenzene and nitric acid. Dithekite 13 is a specific mixture, which is also the most common; the number 13 indicates the percentage of water; i.e., dithekite 13 is composed of nitric acid / nitro benzene / water at a ratio of 63/24/13.

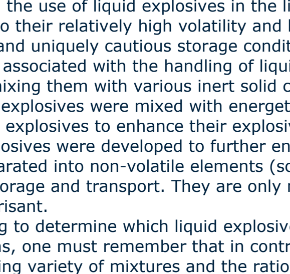
Oxonites are yet another family of mixtures, in which picric acid replaces nitrobenzene.
Additional mixtures based on nitric acid and organic compounds were developed throughout the 20th century: during the 1970s, an emulsion mixture was developed by mixing concentrated nitric acid with ammonium nitrate and stabilizing compounds, resulting in gelatinous explosives and stable emulsions. The drawbacks of these types of mixtures include their corrosive properties, which render their storage and use problematic; as well as the toxicity of dinitrobenzene.

Emulsions

In explosives belonging to the emulsion family the oxidant is introduced in the form of a watery solution into an oily phase by an emulsifier. These substances can be initiated using a detonator after adding gas bubbles, or micro balloons, during the manufacturing process. The main building blocks of these explosives are water, an oxidant, a thickening agent, organic material, and in the case of cap-sensitive explosives – gas bubbles or micro balloons. These substances have a gelatinous paste-like texture and contain other additives, such as aluminum powder.

Water Gel Type Explosives

Substances belonging to this family, which contain a saturated ammonium nitrate solution, were developed with the aim of improving the explosive substances' resistance to water. This was done by adding water together with gelling agents to the explosive substance itself, thus achieving two goals: water-proofing it; and increasing its density to above water density. These enhancements enabled to use these explosives in wet places (mainly boreholes in mines).
Similarly to the emulsion family, cap-sensitive water gel type explosive substances can also be manufactured, by adding materials such as mono methylamine nitrate and other metallic materials, or by adding bubbles and micro balloons.



TOVEX Explosive

Summary

Liquid explosives exist in a variety of colors and densities, as well as in configurations other than the liquid phase – in mixtures of solids, gels and emulsions. The performance level of most liquid explosives, when comparing detonation speed and brisance, is as high as those of solid explosives; however, the use of liquid explosives in the liquid phase is limited, mainly due to their relatively high volatility and high toxicity – limitations that demand uniquely cautious storage conditions and usage.
The safety problems associated with the handling of liquid explosives were overcome by mixing them with various inert solid components. Subsequently, liquid explosives were mixed with energetic solid substances and solid explosives to enhance their explosive properties.
Later on, binary explosives were developed to further enhance safety: the components are separated into non-volatile elements (solid + liquid, or liquid + liquid) for storage and transport. They are only mixed on-site, and thus rendered brisant.
Whenever attempting to determine which liquid explosives are suitable for particular applications, one must remember that in contrast to pure liquid explosives, the existing variety of mixtures and the ratios of their various components require in-depth knowledge.
Note:
Due to the sensitivity of the information included in this review, only partial details were provided concerning the precise mixtures and their methods of preparation. For more detailed information concerning the explosives mentioned above, please contact the author, Avi Icar, through this web site.

About the author:

Mr. Avi Icar is the founder and CEO of A.I. Explosives Inspection & Services. He is an honors graduate of Tel Aviv University's School of Chemistry, and has served as an officer in an Explosive Ordnance Disposal (EOD) Unit of the Israel Defense Forces, and subsequently as an EOD technician and detection technology integrator at the Israel Security Agency.