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Investigating the Effects of Substituting Oil Derivatives instead of Gas Oil in the ANFO Compound

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Abstract

One of the most commonly used explosives in mines is ANFO (Ammonium Nitrate Fuel Oil). This explosive, is made of a combination of a specified percent of gas oil and Ammonium Nitrate, and has been found to be very popular among the mining industry owners and construction projects, because of inexpensiveness and the ease of the production. At present in some small mining projects other oil derivatives like white oil is used instead of oil. In this case, the reaction will not be completed and toxic gases like Nitrogen oxides and carbon monoxide will be produced. On the other hand, failure to complete the reaction process will reduce the energy efficiency of the explosion. Finally, the reduction in the explosion energy will increase the size of the crushed material by the explosion and will reduce the efficiency of upstream operations such as loading and handling. This study investigates the effect of other petroleum derivatives, such as Gasoline and White Oil, N-Hexane, Cyclohexane and Acetone, on the thermal energy released and toxic gas emitted when they are used instead Gas Oil in the combination of ANFO.

Keywords: Explosion; Toxic Gases; ANFO; Energy; Crushing; Mine.

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1. Introduction

Explosives are categorized in the following groups in terms of chemical composition: inorganic compounds, organic compounds, mixtures of combustible substances and oxidizing substances which none of them are explosive per se. Most of the explosive chemical compounds contain hydrogen and nitrogen. To have an explosive, it needs to substitute one or more hydrogen atoms in the raw material with chemical groups. Seemingly, there is no much difference between the chemical formula of an explosive and a non-explosive substance. But the characteristics of explosives are due to the presence of certain specific elements and their molecular arrangements. In the following, the elements of the explosive substances and the role of each one is described.

Nitrogen

It is available in the air in the form of inert and stable gas. When it is combined with another element, it becomes unstable and uncontrollable. It hardly becomes combined and has unstable compounds.

Oxygen

Oxygen is available in explosives in the form of a highly unstable chemical like Nitrate (-NO3), Nitro (-NO2), Nitramin (-NH-NO2), Chlorate (-CLO3), Perchlorate (-ClO4), Foulminc (-ONC). It is easily separated from the above compounds and combined with substances like Hydrogen, Sulfur, or itself to form a stable substance. Some explosives like Nitroglycerine have extra oxygen, and some like TNT have an oxygen deficiency. So, while the

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explosion, they produce smoke. To compensate oxygen deficiency, most often Ammonium Nitrate is added to the explosives. There is an adequate amount of oxygen in the composition of all explosives, as such, explosives burn in closed spaces better.

The difference between the amount of Oxygen available in an explosive and the amount required to achieve a complete explosion reaction is called"oxygen balance". Oxygen balance is an important and significant parameter in the case of explosives. If the difference is zero, it means the amount of available oxygen is adequate for the reaction. If it is lower than the required amount, the object has a negative oxygen balance and the explosion will be incomplete in terms of the chemical reaction. Likewise, if the available oxygen is more than the required amount, the object has a positive balance and due to the explosion, it is released some oxygen or produced toxic nitrogen oxides.

The best explosive is the one with zero oxygen balance. In this way, it is avoided both to produce CO because of the oxygen deficiency, and NO or NO2 because of an extra oxygen amount. The explosives which are used in underground explosion operations have oxygen balance as much as zero or slightly more than zero. We show the atom grams of oxygen in the explosives by O, Hydrogen by H, and Carbon by C. For each atom gram Carbon, 2 atom grams of oxygen and for each atom gram of Hydrogen 0.5 atom gram Hydrogen are consumed, so the above-mentioned can be written as follows:

$O - 2C - \frac{1}{2}H = 0$ Zero balance

$O - 2C - \frac{1}{2}H < 0$ Negative balance

$O - 2C - \frac{1}{2}H > 0$ Positive balance

To express the quantity of the oxygen balance, the formula for the explosive reaction is considered in the ideal conditions, and then the lack or the excess of oxygen in the explosive is calculated. An ideal condition is a condition which lets to form CO2, H2O, and AL2O3. The ratio of excess or lack of oxygen to the mass of the explosive is called oxygen balance.

Carbon

Carbon is one of the combustible substances in the explosives, which releases gases and heath by combustion. If the oxygen balance of the explosive is negative, incomplete combustion of carbon occurs and the heat released is lower than the case of which the oxygen balance is positive.

Hydrogen

The combustion of Hydrogen produces heat and H2O gas.

Metal elements

Elements like Mercury, Lead, and Aluminum are used in the construction of the explosives and they form unstable molecular nuclei. Addition of Aluminum to an explosive compound increases its energy.

2. ANFO and its compound

ANFO, which consists of the first letters of the "Ammonium Nitrate Fuel Oil" words, means the mixture of Ammonium Nitrate and liquefied fuel. Ammonium Nitrate is used in many of explosives, as an oxidizing agent. One of the explosives which are made of Ammonium Nitrate is its mixture with liquid fuel, which is widely used in mining because of being inexpensive and highly safe. In general, ANFO contains 94.5% Ammonium Nitrate, which its seeds are covered with anti-lay and 5.5% liquid fuel. The physical properties of ANFO are given in table 1.

Table 1. Physical properties of ANFO produced in Iran

Brand name	Density (g/cm3)	Water resistance	Explosion speed
ANFO	0.85-1	Weak	3200

3. The investigation of the liquid fuels, which are substituted instead of gas oil in the combination of ANFO

In this section, fuels which are substituted instead of gas oil in the combination of Ammonium Nitrate to make explosives (include gas oil (CH2), Gasoline (C8H18), White Oil (c12h26), Acetone (ch3coch3), Cyclohexane (c6h12), n-Hexane (c6h14)) are presented in the view of thermal energy produced, weight ratio used for achieving oxygen balance and the fixed price of the produced explosive based on this percent is presented.

3.1 The investigation of oxygen balance

In this section, the way of combining every one of the above mentioned fuels with Ammonium Nitrate, in the way that oxygen balance is maintained, is balanced. The results of these reactions are presented in table 2.

Table 2. The oxygen balance of fuels

Fuel type	Chemical reaction
Gas oil	$3NH4NO3 + CH2 \rightarrow CO2 + 7H2O + 3N2$
Gasoline	$25NH4NO3 + C8H18 \rightarrow 8CO2 + 59H2O + 25N2$
White petroleum	$37NH4NO3 + C12H26 \rightarrow 12CO2 + 87H2O + 37N2$
Acetone	$8NH4NO3 + CH3COCH3 \rightarrow 3CO2 + 19H2O + 8N2$
Cyclohexane	$18NH4NO3 + C6H12 \rightarrow 6CO2 + 42H2O + 18N2$
N-hexane	$19NH4NO3 + C6H14 \rightarrow 6CO2 + 45H2O + 18N2$

3.2 The calculation of weight percent

On table 3 the weight percent of the fuels which are substituted instead of gas oil in the combination of Ammonium Nitrate to make an explosive is presented with regard to the balancing coefficients from table 2.

Table 3. The weight percent of liquid fuels

Fuel type	Weight percent
Gas oil	$\frac{14}{240 + 14} \times 100 = 5.5\%$
Gasoline	$\frac{114}{2000 + 114} \times 100 = 5.4\%$
White oil	$\frac{170}{2960 + 170} \times 100 = 5.4\%$
Acetone	$\frac{58}{640 + 58} \times 100 = 8.3\%$
Cyclohexane	$\frac{84}{1440 + 84} \times 100 = 5.5\%$
N-hexane	$\frac{86}{1520 + 86} \times 100 = 5.3\%$

3.3 Thermo-chemical properties of explosion

In each system which absorbs or disposes energy, the total amount of energy is constant, but it appears in different shapes.
Constant = kinetic energy + potential energy

3.4 The heat released from the explosion in constant pressure

When an explosion occurs in the constant pressure, the only thing that happens is the air displacement surrounding the explosion area. The released heat can be obtained from the relation $Q = -\Delta H$ and it is equal to variations in enthalpy and it is calculated based on the following relation:

Q = The heat resulted from the formation of the explosion products QP – The heat resulted from the formation of the explosive QE

The "heat of formation" is the amount of heat which is absorbed or produced during a chemical reaction.

3.4.1 The released heat from reactions

The heat released from every one of the reactions was calculated and given in table 4.

Table 4. the heat released per one gram ANFO

Fuel type	The released heat
Gas oil	$3NH4NO3 + CH2 \rightarrow CO2 + 7H2O + 3N2 + 900cal/gr$
Gasoline	$25NH4NO3 + C8H18 \rightarrow 8CO2 + 59H2O + 25N2 + 914.26cal/gr$
White oil	$37NH4NO3 + C12H26 \rightarrow 12CO2 + 87H2O + 37N2 + 909.83cal/gr$
Acetone	$8NH4NO3 + CH3COCH3 \rightarrow 3CO2 + 19H2O + 8N2 + 890.26cal/gr$
Cyclohexane	$18NH4NO3 + C6H12 \rightarrow 6CO2 + 42H2O + 18N2 + 909cal/gr$
N-hexane	$19NH4NO3 + C6H14 \rightarrow 6CO2 + 45H2O + 18N2 + 910cal/gr$

3.5 The economic situation of fuels

With regard to the weight percentages obtained from table 3, the price for every fuel in the country is according to table 5.
The weights of the fuels and Ammonium Nitrate for ANFO the combination and the final price of the combined fuel is given in table 6.

Table 5. The price of fuels in the country

Fuel type	Unit (mL)	Price (Rials)
Gas oil	1000	3000
Gasoline	1000	10000
White oil	1000	1500
Acetone	1000	750000
Cyclohexane	1000	3876000
N-hexane	1000	455000

Table 6. The final price of combined fuels

Fuel type	Ammonium Nitrate weight (gr)	Fuel weight (mL or gram)	ANFO weight (gr)	The combined fuel price (Rials)
Gas oil	240	14	254	42
Gasoline	2000	114	2114	114
White oil	2960	170	3130	255
Acetone	640	58	698	43500
Cyclohexane	1440	84	1524	325584
N-hexane	1520	86	1606	39130

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