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Fuel Air Explosives

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ABSTRACT

In this paper, important features of Fuel Air Explosives studies on different performance parameters, namely, minimum initiation energy, fuel droplet size, sensitivity to detonation etc. and current trends in this field of research have been briefly discussed.

1. INTRODUCTION

The high explosives (solid) in the warheads, in general, are characterised by detonation waves of very high pressure and very short duration producing fast decaying blast waves, resulting in low impulse and hence less damage to targets at longer distances. Efforts to develop new explosives with blast waves of greater impulse led to metallised explosives like tritonal and torpex etc. The increased blast durations in these cases are due to late stage reactions of the metal with the explosive.

However, a significant advancement in this field is the finding that certain hydrocarbons and their oxides form detonable aerosols with air over a wide range of concentrations known as Fuel Air Explosives (FAE). These systems yield very high impulse on detonation due to their higher heats of combustion and greater specific volume. For example, heat of combustion and specific volume of ethylene oxide are 6 and 800 times that of TNT respectively. By virtue of their gaseous state before detonation, FAE covers larger area with no inhibition by land contour or protective structures. According to Smith, etal.[1], a typical FAE based on ethylene oxide has a TNT equivalent of 2.7 to 5.0.

Oxygen/air mixtures of a number of hydrocarbons have been studied by many workers. However of these only methane, ethylene oxide, propylene oxide and MAPP (methyl acetylene propadiene and propane mixture) found use in military applications.

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Since 1960, USA has been working in this field and has developed a number of FAE based weapons[1,2,3] such as 500 lb CBU-55 B Cluster Bomb and SLUFAE rocket system for mine breaching. Their work included studies at simulated high altitudes and in under water for application in Anti-Ballistic Missiles and Anti-Ship Missiles etc. and even for replacement of nuclear warheads. FAE has also been used as a blast simulator for small yield nuclear weapons. Though USSR has been reported to have a large arsenal of FAE weapons[1,4] , much information is not available in the open literature.

2. MECHANISM OF FAE INITIATION

There are two modes of initiation viz., self initiation and direct initiation in systems, wherein both the fuel and oxidizer are gases.[5] In self initiation mode, a flame generated by spark gap or glow wire in the mixture is self-accelerated to turbulent state and its further amplification leads to ultimately detonation. In direct initiation mode, a shock wave generated by a powerful igniter source, produces detonation instantaneouslyin the mixture. The essence of these modes is the generation of critical states for detonation, which correspond to those at the auto-ignition limit of the mixture.

On the other hand, in liquid fuel gaseous oxidizer system[6-14], a shock wave generated by the igniter source causes mass removal from the periphery of the fuel droplet.

Table 1. Detonation parameters for a number of stoichiometric fuel air explosives. Initial pressure – 101.325 Pa: Initial temp – 298°K

Fuel	Explosive limits by vol. (%)	Auto ignition temp (°K)	C.J. detonation parameters			Reported pressures (1) inside the detonation zone (MPa)
			Pressures (MPa)	Velocity (m/s)	Temp. (°K)	
Methane	5-15	713	1.742	1802	2784	2.3
Acetylene	2.5-100	578	1.939	1864	3114	-
Ethylene oxide	3-100	702	1.963	1831	2949	3.2
Propylene oxide	3-27.5	738	1.980	1826	2930	1.8
n-Heptane	1-7.0	595	1.889	1800	2828	
Heptane+ 10% n.propylnitrate	-		1.902	1803	2835	
Heptane+ 20% n.propylnitrate			1.917	1806	2843	

This results from the droplet inertia against the high speed flow set up by the shock wave. Liquid stripped from the droplet enters the wake area in the form of microspray, which then rapidly evaporates. The gradual accumulation of micromist in the wake ultimately forms an explosive mixture, which produces blast waves on detonation. The blast waves emitted from many such droplets coalesce into a stronger shock which initiates detonation. Due to droplet break up process, two phase mixtures have longer ignition delays than that of gaseous mixtures. The detonation states of FAE can be predicted by one dimensional Chapman-Jouguet theory. The computed detonation states at stoichiometric concentrations for a number of fuels are given in Table 1[15,16].

3. PARAMETRIC STUDIES

The performance of any FAE mainly depends on the following parameters :

1. Minimum energy for initiation
2. Droplet size
3. Chemical behaviour of the fuel
4. Effects of additives on fuel sensitivity to detonation

3.1 Minimum energy for detonation

A minimum shock energy[7] for certain time period is required to initiate FAE detonation, below which only flame is generated. Theoretical studies[5] show that shock strengths of 4 and 5 Mach are required for directly initiating gaseous and two phase mixtures respectively. Experimental studies on gaseous fuels[6] have shown that acetylene requires minimum quantity of 1.0 to 2.0 gm of tetryl charge for initiation and methane is very much insensitive to detonation. The values of initiation energies and auto-ignition temperature (AIT) of various fuels, shown in Table 2, indicate that, generally,[6] initiation energies are directly proportional to AIT.

Table 2. FAE minimum energy for initiation.

Fuel in air at stoichiometric conc.	AIT (°K)	Tetryl charge required for initiation (g)	Velocity of detonation(m/s)	
			Theoretical	Experimental
Methane	713	22×10³☆	1802	-
Ethane	788	30-40	1800	1760
Propane	723	50-80	1797	1800
Isobutane	-	80-100	1794	1793
Ethylene	763	10-15	1822	1780
Acetylene	578	1.0-2.0	1864	

☆Extrapolated value

3.2 Droplet size

In the case of two phase FAE mixtures, droplet size plays an important role in addition to the minimum shock energy for direct initiation. More the droplet size, more is the explosive charge quantity required for initiation, as shown in Table 3.

Table 3. FAE (Hexane) - Effect of drop size.

Drop size (μm)	Eq. ratio(fuel/air)/ (fuel/air)St.	Tetryl charge required for initiation (g)	Experimentally observed VOD (m/s)
6 - 17	1.1 - 1.2	30	1580
50 - 90	1.1	55	1300

Studies of Bull. et al[7]. have shown that finer aerosol mixtures of hexane are more sensitive, requiring lesser tetryl charge for initiation and produce higher velocity of detonation in the mixture.

3.3 Chemical behaviour of the fuel

Examination of the sensitivity data of different fuels, having similar physical properties, indicates that fuels of lower bond energy are more sensitive for detonation. For example, acetylene containing triple bond is more sensitive than ethylene or ethane since the energy required to activate a triple bond is low. Studies of Lu, et al.[8], on different fuels such as ethyl nitrate, propyl nitrate, nitromethane, butyl alcohol, nitrobenzene and diethyl cyclohexane (DECH) with similar physical properties but different chemical behaviour, have shown that only ethyl nitrate and propyl nitrate having lowest bond energies, are ignited in pure oxygen atmosphere with a shock velocity of about 3.3 Mach.

3.4 Effect of additives on fuel sensitivity to detonation

Studies have shown that fuels with longer ignition delays can be initiated either by reducing their droplet size or by inclusion of chemical additives. In the case of chemical additives, free radicals generated are attributed to speed up the chain reactions and thereby lower the ignltion delays. The ignition delay of methane was decreased by 50-60 per cent by the addtion of 1-2 percent of NO_2 at temperature range of 1300-1800°K[9]. Studies of Lu, et al[10]., with heptane aerosols of different droplet sizes (1400 , 700 and 10 μm) have shown that hexane aerosol of 1400 μm droplet size, which is normally not detonable, has been detonated by addition of 25 per cent normal propyl nitrate (Table 4).

Table 4. **FAE (Heptane) - effect of additive on sensitivity.**

FAE Aerosol + chemical additive	Drop size		
	(1400 μm)	(700 μm)	(Fog - 10 μm)
Heptane	ND	ND	D
Heptane+10% NPN	ND	D	D
Heptane+20% NPN	-	D	D
Heptane+25% NPN	D	-	

NPN -Normal propyl nitrate; ND - No detonation; D - Detonation

4. SELECTION OF FUEL FOR FAE MUNITIONS

The selection of fuel for FAE munitions mainly depends on the requirement. In general, the fuel must have wide range of explosive limits in air, high sensitivity to detonation, sufficient damage potential and good storage stability. Ethylene oxide initially used in FAE warheads in USA has been subsequently replaced by propylene oxide to overcome the storage problems. Heptane with 20 per cent normal propyl nitrate[10] forms detonable mixtures with air in a wide range of concentrations and covers a larger area as compared to propylene oxide. This mixture has higher heat of combustion and produces higher blast effectiveness. This combination is considered to be the fuel for future FAE munitions.

5. CURRENT TRENDS

Fuel Air Explosion is presently a two event process., viz, dispersion of fuel in air and detonation of the fuel air cloud. Current emphasis is to make it a single event process with the elimination of second event requirement. In single event process the fuel and the initiating chemical (catalyst) are dispersed simultaneously to form a vapour cloud. The catalyst reacting with either the fuel or oxygen in the air produces free radicals to initiate explosive mixture. Several workers[17,18] have achieved success with the concept of single event FAE. Injection of gaseous pyrophoric fuel, dimethyl zinc, in an equi-molar oxy-acetylene mixture has been reported to initiate the detonation in the mixture. Current efforts are under way to achieve more detailed qualitative/quantitative data of this phenomenon.

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