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Research Article

EFFECT HIGH EXPLOSIVE TYPE ON THE PERFORMANCE OF SHAPED CHARGE USED IN OIL INDUSTRY

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ABSTRACT

Several explosives have been tested numerically to study their effect and performance of the produced jet characteristics and predicted jet penetration into concrete target material. TNT, cyclotol, RDX, HMX, PETN and LX-17 have been used in this research as a shaped charge oil well perforator, where the Autodyn hydrocode has been implemented with the jetting analysis solver and jet penetration to estimate both the jetting output data and the relevant penetration depth for these studied explosives. Results show that HMX explosive exhibiting the highest detonation velocity, has the largest penetration depth into Concrete 26MPa target. The relative jet tip velocity to the Gurney characteristic velocity of an explosive has been found to be around 2.5 for the used explosive charges, whereas the scaled jet tip velocity to the detonation velocity of an explosive has been found to be one for the studied six explosives.

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1. INTRODUCTION

Shaped charges have wide range of application such in civilian applications as Oil industry as oil well perforator, Explosive ordnance disposal, Cautious blasting and demolishing works, Break, crack or form holes in rocks, Explosive welding and Generation of transient antennas to countermeasure the use of electromagnetic pulse (EMP) weapons [1]. On the other side, shaped charges are extremely useful for penetrating armor or piercing barriers in the field ofmilitary applications. It can be used as a part of torpedoes, missiles or particularly as an anti-tank ammunition. Its military application started from World War II when the so-called hollow chargeprojectiles were proposed. Figure (1) shows schematic drawing of a shaped charge configuration. The shaped charge geometry design and the liner thickness are the most effective parameters governing the performance of a shaped charge [2]. Apart from its cone diameter;

conical shaped charge (CSC) liner performance in terms of its breakup time is governed and controlled by various factors [3] as the production method of the liner material, quality of both the inner and outer surfaces of the copper liner, quality of both the inner and outer surfaces of the copper liner, the adhesive material between copper and high explosive materials, the type of thehigh explosive, and amount of it as well as other parameters such as the presence of air cavities inthe explosive material and any eccentricity of the shaped charge elements.

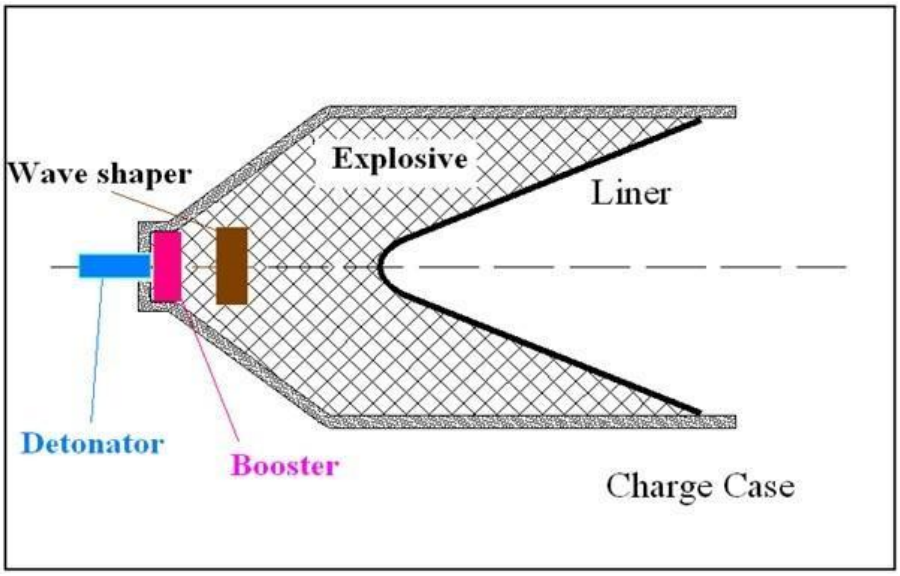

Fig.1. A schematic drawing of a shaped charge configuration

2. DESCRIPTION OF THE HIGH EXPLOSIVE

Theoretically, more energetic explosive produces faster jet, greater jet kinetic energy and deeper penetration [4]. The energy obtained from the high explosive during its detonation is related to Gurney constant of this explosive, which is the energy liberated from the high explosive and transformed into mechanical work imparted to the liner element. Gurney velocity increases as the detonation velocity and/or the detonation pressure of the explosive, which leads to the increase of the jet tip velocity. As a result, the jet kinetic energy and its penetration potential into target will be enhanced.

Table 1 illustrates the explosive properties of some high explosives. It is expected that shaped charges filled with HMX, which has the highest Gurney velocity, will produce higher penetration depth, as shown by Tamer and Li [5].

Table 1. Explosive properties for some high explosives

Parameter H.E.	Density ρ (g/cm^3)	Detonation velocity (m/s)	Gurney velocity (m/s)	Explosion heat (kJ/kg)	Detonation pressure (GPa)	Ignition Temp. (^{o}C)
HMX	1.891	9100	2960	5553	420	280
LX-14 (HMX/Estane)	1.835	8800	2800	5559	370	NA
RDX	1.73	8489	2870	4118	330	210
Cyclotol (RDX/TNT) 75/25	1.754	8250	2790	5245	320	NA
PETN	1.72	8142	2920	5770	220	202
TNT	1.6	6913	2390	3681	210	227

The Gurney constant for Cyclotol was obtained from [6], while the ignition temperature was obtained from ref. [7]. It is also known that the penetration depth of the shaped charge jet into concrete material increases with the increase of the amount of high explosive used in the shaped charge, which also causes the increase of the damage of the crushed region around the penetration path [8].

The selection of high explosive in the design of gun perforator is very important for bothits performance and sensitivity issues. The temperature of the down-hole can be greater than 260 ^{o}C [9], which should be considered because it is close to the ignition temperatures of some high explosives. Therefore, care should be taken in the design of the main explosive charge andthe degree of casing confinement.

Another important issue related to the high explosive filling of the OWP is the manufacturing technique. The explosive density, the presence of air bubbles and cracks inside the explosive also affect the performance of OWP. The explosive should be pressed under vacuum to remove air bubbles and to increase its density, as shown by Renfre et al. [10].

Moreover, shaped charges used in military purposes should be checked by flash X-ray for air voids and cracks. Other parameters such as grain size and homogeneity of high explosives should also be considered [4]. Moreover, it has been claimed that the shaped charge warhead may be expected to perform much more effectively and efficiently when the filling explosive has a particle size less than 200μm [11].

3. NUMERICAL CALCULATIONS

Numerical simulation is one of the main methods used to study the penetration phenomenon, which can be used to solve nonlinear problems related to impact, penetration, perforation and explosion. It has built-in mathematical models such as shaped charge jetting analysis [12]. Autodyn hydrocode is based on mass, momentum and energy conservation equations, where the materials can be defined by its equation of state and its strength model [13]. This hydrocode is capable of performing the shaped charge jetting analysis, jet formation and penetration into concrete materials. The jetting analysis is based on both the numerical finite difference technique to calculate the collapse velocities and the analytical unsteady PER theory [8] to calculate the jet and the slug velocities and masses as well as the collapse and the deflection angles of the liner elements. In this algorithm, the liner is described as a thin shell composed of a series of nodes having the real thickness of the liner, while its apex point should befixed by a boundary condition to prevent its motion [12]. The jet formation is simulated using Euler method based on continuum mechanics to obtain the jet profiles at different time stages. In this scheme, the explosive, the charge casing and the liner materials are filled into the global Euler multi-material part [13]. This processor is suitable in the early jet formation stages, where large distortions will be caused by extremely high strain-rate in the order of $10^7 s^{-1}$ [14].

The jet interaction (penetration) with the laminated target layers is simulated using Lagrange method. In this scheme, the jet obtained from the jet formation Euler solver is remapped to Lagrange moving grids and affects the multi-layered target. To overcome the mesh distortion problem in Lagrange solver, a mesh discard option or “erosion strain” is applied to the jet and the target materials. The erosion strain does not represent a physical phenomenon, but a numerical algorithm to prevent the mesh distortions.

The used shaped charge has a conical copper liner of angle 45 degree, a wall thickness of 1.4mm and a charge caliber of 36.6mm, while the charge casing is made of steel 4340

The values of the experimental constants for some explosives have been determined from the sideway-pushing-plate test [14] and the cylinder expansion test. These constants are given in table 2 for the studied explosive materials.

Table 2. Input data to the code for the used explosive materials

Parameter	Explosive Type					
	TNT	HMX	Cyclotol	LX-17	PETN	RDX
Density (g/cm^3)	1.630	1.891	1.754	1.900	1.500	1.600
Parameter A (kPa)	3.740×10^8	7.782×10^8	6.034×10^8	4.46×10^8	6.253×10^8	6.539×10^8
Parameter B (kPa)	3.747×10^6	7.071×10^6	9.923×10^6	1.3×10^6	2.32×10^7	7.293×10^7
Parameter r1	4.15	4.2	4.3	3.85	5.25	4.83
Parameter r2	0.9	1	1.1	1.03	1.6	2.24
C-J detonation velocity (m/s)	6930	9100	8250	7600	7450	8100

C-J energy per unit volume (kJ/m^3)	6.00×10^6	1.05×10^7	9.2×10^6	6.9×10^6	8.56×10^6	5.62×10^6
C-J pressure (kPa)	2.1×10^7	4.2×10^7	3.2×10^7	3.0×10^7	2.2×10^7	2.6×10^7
Parameter ω	0.3	0.3	0.35	0.46	0.28	0.3

The EOS of the copper liner material (as well as the casing and target materials) is the shock model, while its strength model is neglected due to the extremely large pressure on the liner wall during liner collapse [13]. It has been shown experimentally that for most solids and liquidsthat do not undergo a phase change, the values of shock velocity (U) and material velocity behindthe shock (Up) on shock Hugoniot can adequately fit to a straight line.This is valid up to shock velocities around twice the initial sound speed C_o and shock pressures in the order of 100 GPa [13].The mechanical properties of the copper liner material and the Johnson cook strength model forsteel 4340 are shown in table 3.

Table 3. The mechanical properties of liner and the casing materials [18]

Parameter	Copper C10100	Steel 4340
Equation of state	Shock	Shock
Reference density (g/cm^3)	8.93	7.83
Gruneisen Coefficient	2.02	1.93
Parameter C (m/s)	3940	4569
Parameter S (non)	1.489	1.4
Ref. temperature (K)	300	300
Strength	None	Johnson cook
A (MPa)	-	792

B (MPa)	-	510
n (non)	-	0.26
C (non)	-	0.014
m (non)	-	1.03

Table 4. Input data to the code for the charge casing material [13].

Reference density (g/cm^3)	7.83
Tensile strength (MPa)	744
A (MPa)	792
B (MPa)	510
n (non)	0.26
C (non)	0.014
m (non)	1.03
Gruneisen coefficient	1.93
Parameter C1 (m/s)	4569
Parameter S1 (non)	1.4

4. STUDIED PARAMETER

Amount of high explosive: different types of explosives (TNT- PETN-LX-17- RDX-Cyclotol- HMX). Gurney energy or Gurney velocity is a measure of explosive power or its efficiency. The higher the Gurney energy, the higher the velocity of the produced jet, and hence the higher the penetration capability of the shaped charge. Table 5 shows the properties of the explosives related to their type.

Table 5. Explosive type properties

Explosive properties			
Explosive	**ρo (g/cm^3)**	**D(m/s)**	**Qv (kJ/kg)**
TNT	1.63	6930	3681
PETN	1.50	7450	5707
LX-17	1.90	7600	6900
RDX	1.73	8100	4118
Cyclotol	1.75	8250	5245
HMX	1.89	9100	5553

5. RESULTS

Figure 2 shows the dependence of the jet tip velocity and the Gurney velocity on the explosion heat of the used explosive charge.

The details of the used explosives and the produced jet characteristics obtained from standard jetting analysis are listed in table 6. The relation between the jet tip velocity and the detonation velocity of the explosive is illustrated in Figure 3.

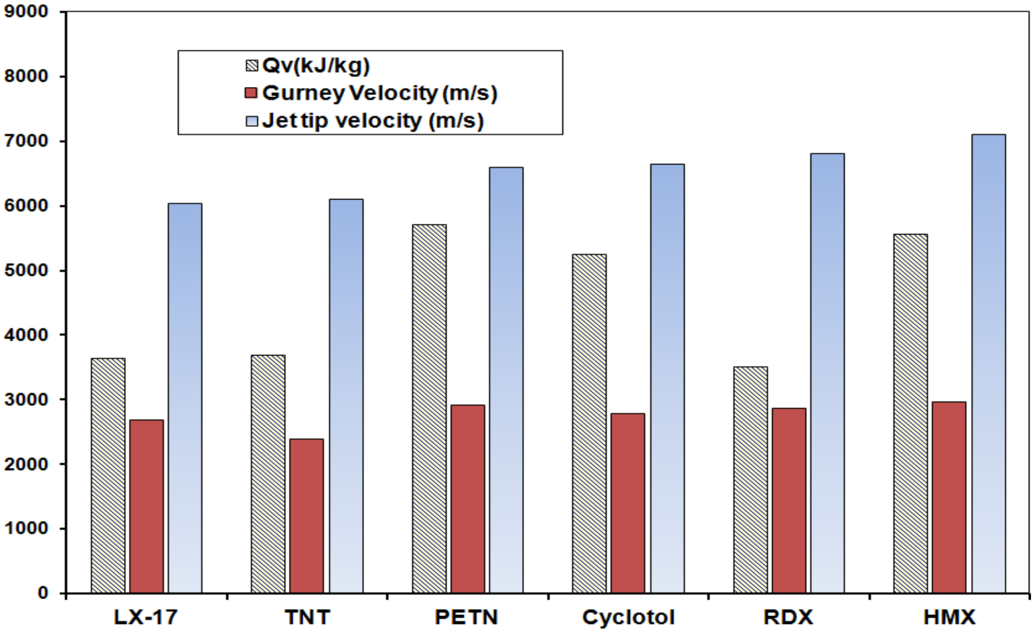

Fig.2. The dependence of jet tip velocity and Gurney velocity on the explosion heat of explosives

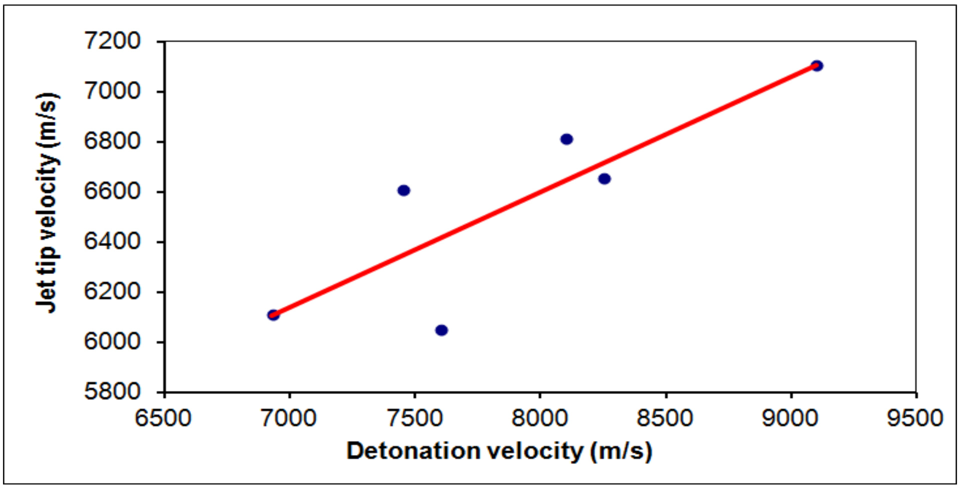

Figure 3. The relation between the jet tip velocity and the detonation velocity of the used explosive

It shows that the most powerful explosive is HMX, which has a Gurney velocity of 2960m/s and detonation velocity of 9100 m/s. This explosive produces a jet tip velocity of 7103m/s and a jet mass ratio of 17.76% as shown in table (6).This result was confirmed by the jet formation model and penetration model tests where the OWP filled by HMX produced the largest penetration depth of 74.88 cm.

Table 6. Effect of the explosive type on the jet characteristics of 46° conical copper liner of wallthickness of 1.4mm and 29.32g liner mass and steel casing thickness

Explosive	**Output**			
	Jet mass (g)	**Jet %**	**Jet tip vel. (m/s)**	**Jet K.E. (kJ)**
TNT	5.45	16.47	6108	38.19
PETN	5.33	16.10	6605	49.70
LX-17	5.73	17.30	6046	36.06
RDX	5.68	17.16	6813	44.59
Cyclotol	5.82	17.59	6652	43.35
HMX	5.89	17.76	7103	44.00

Table (7) lists the penetration depths, jet tip and tail velocities and exit hole diameter of the different OWP obtained from jet formation and penetration models using different explosive charges.

Table 7. The jet output data and penetration results of shaped charge with 46° cone apex angle,1.4mm liner of thickness using different filling explosive charges into 35 MPa concrete target

Parameter	**Explosive Type**					
	TNT	**Cyclotol**	**RDX**	**HMX**	**PETN**	**LX-17**
Jet breakup time (µs)	56.38	54.00	52.20	46.00	53.70	58.00
Jet tip velocity (m/s)	6108	6652	6813	7103	6605	6046
Jet momentum (kg.m/s)	15.46	16.64	16.78	15.03	17.72	15.05
Jet tail velocity (m/s)	722	744	656	709	815	674
Penetration depth (cm)	60.96	64.38	71.20	74.88	72.90	66.80
Exit hole diameter (mm)	12.04	16.24	18.80	14.00	19.80	15.52

Note: LX-17 is a mixture of 92.5% TATB and 7.5% Kel F binder

The scaled jet tip velocity to the detonation velocity and the Gurney velocity of the explosive are shown in figure (4) as a function of detonation velocity of the used explosive. It can be concluded that these ratios are nearly constant for the used six explosives. The scaled jet tip to explosive detonation velocity ratio is 0.82, while the scaled jet tip to the Gurney velocity ratio is 2.38. This indicates a nearly constant ratio of jet velocity to the explosive detonation characteristics over a wide range of explosive materials.

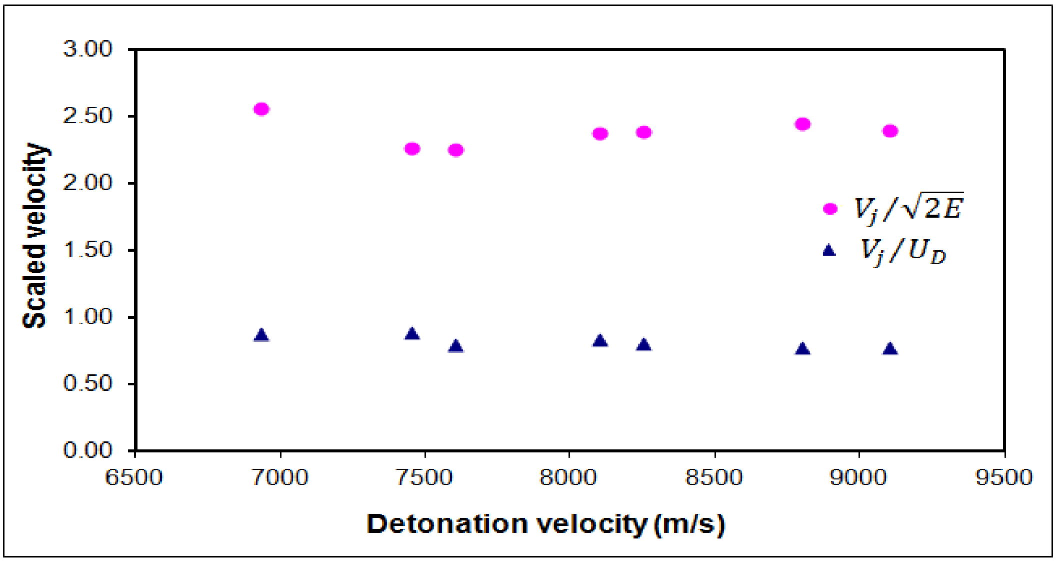

Fig.4. The ratio of the jet tip velocity to the detonation velocity and the Gurney velocity of the used explosives

6. CONCLUSION

The most powerful explosive; HMX, which has a Gurney velocity of 2960m/s and detonation velocity of 9100 m/s was found to have the best performance form jetting analysis andits highest penetration performance into concrete target in comparison with other studied explosives. The high values of both Gurney velocity and detonation velocity produces a jet tip velocity of 7103m/s, which achieved the largest penetration depth of 74.88 cm into concrete targets. The scaled jet tip velocity to the Gurney characteristic velocity of an explosive has been found to be around 2.5 for the used explosive charges, whereas the scaled jet tip velocity to the detonation velocity of an explosive has been found to be one for the studied six explosives.

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