DESIGN OF SHAPED CHARGE AS OIL WELL PERFORATOR

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Summary Shaped charge used in oil industry is termed oil well perforator (OWP) and is used to connect oil and gas to the reservoir by making deep holes into the geological wellbore. Upon detonation of an OWP, it produces jet at hypervelocity around 10km/s and a slug at velocity around 1km/s. The performance of OWP is tested by firing it against the standard concrete target representing the geological boreholes according to API-RP43. This paper identifies the dominant parameters that influence the jet formation and thus the performance of an OWP. These parameters include the selection of high explosives, the selection of liner materials and the shape of liner. Based on these analyses, the design of an OWP is discussed.

INTRODUCTION

Shaped charges have been widely used in both military and civilian applications [1]. It can be used in anti-tank rockets as a military application, while its civilian usage includes explosive ordnance disposal, cautious blasting, demolishing works and oil and gas well perforators. When the shaped charge is detonated, its liner will collapse towards the liner axis forming the front jet and the rear slug. Most of the target penetration is achieved by the hypervelocity jet, while the slow slug determines the diameter of the penetration hole. Thus, the liner is considered as the most critical element affecting the performance of the shaped charge in terms of its penetration capability into target material [2]. In this paper, the performance of a certain OWP is enhanced using three different liner shapes and two other liner materials. The target used to evaluate the performance of these OWP is illustrated in Fig.1 according to API-RP43 (Section II: target section) [3].

LINER MATERIAL

Theoretically, the higher the kinetic energy of the jet, the more the penetration will be achieved. The kinetic energy can be increased either by increasing the jet density or by increasing its velocity. The jet density has a direct effect on the penetration depth (P_D) according to the hydrodynamic equation [4]:

$$P_D = (V_j - V_c)t_b\sqrt{\frac{\rho_j}{\rho_t}}$$

where V_j and V_c are the jet tip and tail velocities, respectively, t_b is the breakup time, ρ_j and ρ_t are the jet and target material densities respectively. Other aspects of the same type of liner material are important and can make a big difference in the performance such as the material ductility, the grain size, the present impurities and the method of production. This study will include three different liners produced by three different methods. The first one is the copper OFHC liner produced by multi-stages deep drawing technique with intermediate annealing stages. The second is a solid annealed Zirconium liner 99.99 purity produced from solid cylinder using CNC machine. The Third one is the powder mixture liner produced from Copper-Tungsten, Tin, solid Graphite particles mixtures produced by the well-known powder metallurgy technique [5, 6]. All the three liners have the simple conical shape, but have different masses according to their densities. The used explosive with these liners is PE4 of about 41 grams.

LINER SHAPE

The liner shape determines the characteristic of the generated jet, the produced crater depth and its hole diameter [2]. For example, the hemispherical liner produces a shallow depth of penetration, but with greater hole diameter. In general, the geometry of the cone is determined by the cone apex angle. If this angle is small, then the jet is very fast, but its mass will be very small [1]. Thus, its total kinetic energy should be considered when this liner is compared with another one. The simple conical liner could be modified to the 'Bell shape', in which vertical distance is increased between the liner portions and its axis in the apex region. This distance is needed to accelerate the apex liner elements to its theoretical maximum velocity; therefore its kinetic energy will be higher than the conical liner baseline [3]. The three liner shapes that have been tested are the conical, the hemispherical and the bell shape. These liners were manufactured from pure solid Zirconium using CNC machine. All these liners are illustrated in Figs. 2 and 3, in which all the calculated data are listed in Table 1.

Table 1. The calculated data for the six liners (the jet characteristics were calculated using Autodyn [7]).

Parameter	Liner material			Liner shape (Zirconium)		
	Copper	Powder	Zirconium	Conical	hemispherical	Trumpet
Density (g/cm^3)	8.93	11.2	6.25	6.25	6.25	6.25
Kinetic energy (kJ)	36	34	39.2	39.2	26	44
Penetration (relative to copper)	1	1.15	1.25	1.25	0.9	1.33
Cost with respect to Copper	1	0.3	5	5	4	6
Production time relative to copper	1	0.2	10	10	4	12

RESULTS AND CONCLUSIONS

The liner shape and its material have significant effects on the performance of OWP in terms of its penetration depth into the tested concrete target. The pure annealed Zirconium is a ductile material [8] and can achieve a deeper penetration depth than copper, but its manufacturing and material costs will eliminate its wide usage. Instead, the powder metallurgy liners could be the optimum because its cost is much lower than that of copper and zirconium, but it has a better penetration capability than copper. In addition, it is not time consuming when compared with other two types in the mass production. Moreover, it does not clog the wellbore because of its porous slug, which is considered the main reason of clogging wellbore problems when a solid copper is used as a liner.

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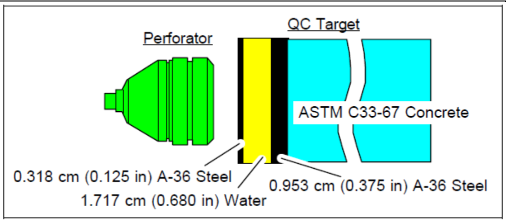
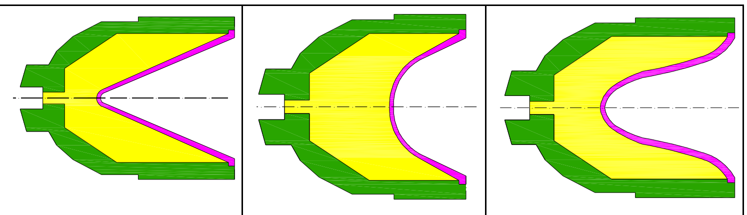


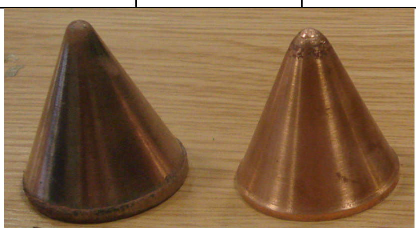
Fig. 1. The test setup for testing OWP due to API-RP43



Baseline conical liner | Hemispherical liner | Bell shape liner

Fig. 2. The three liner shapes

The conical | The Bell | The hemispherical



The powder pressed liner | The drawn copper

Fig.3. The tested liner shapes

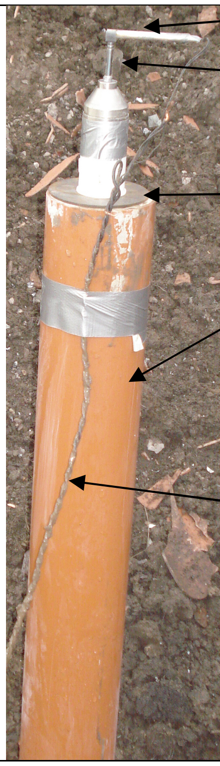


Fig. 4. The test setup

Fig. 5. A sample of test results