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DEVELOPMENTS IN PETROLEUM SCIENCE

WELL COMPLETION DESIGN

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- Ability to add zones at a later date. It is also possible to reperfurate zones plugged by scales and other deposits.
- Suitable for fracture stimulation, especially where fracture containment or multiple fracturing is required.
- Reduced sanding potential through perforations being smaller than a wellbore, selective perforating or oriented guns (Section 3.2.1, Chapter 3).
- Ease of application of chemical treatments – especially those treatments requiring diversion such as scale squeezes, acidisation and other chemical dissolvers.
- Ease of use with smart completions or where isolation packers are used, for example with sliding side doors (SSDs).

The main disadvantage is the increased costs, especially with respect to high angles or long intervals.

Although many years ago bullet perforating was used to open up cased and cemented intervals to flow, a vast majority of perforated wells now use the shaped charge (sometimes called jet perforators). The bullet perforator still finds a niche application in creating a controlled entrance hole suitable for limited-entry stimulation (Section 2.5.2). The shaped charge was a development for armour piercing shells in the Second World War. It creates a very high pressure, but a highly focussed jet that is designed to penetrate the casing, the cement and, as far as possible, into the formation.

The components of the shaped charge are shown in Figure 2.34, with a typical configuration inside a perforation gun shown in Figure 2.35.

The amount of explosive used is small – typically in the range of 6 to 32 g (0.2–1.1 oz), although smaller charges are available for very small-diameter casing and larger charges can be used for big hole charges (cased hole gravel packs).

The explosive energy of the detonation is focussed in one direction by the conical case. This reflects a lot of the energy back into a narrow pulse. The relatively thin charge liner also plays a critical role by systematically collapsing and emerging as a high-velocity jet of fluidised metal particles. The pulse moves out at around 30,000 ft/sec (20,000 miles/h) and generates pressures between 5 and 15 million psia.

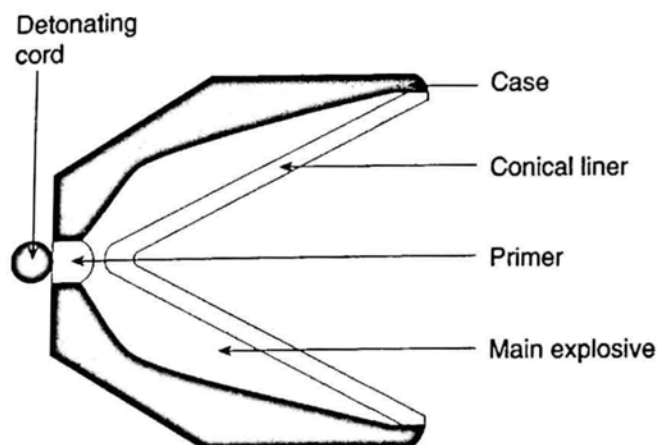


Figure 2.34 Shaped charge.

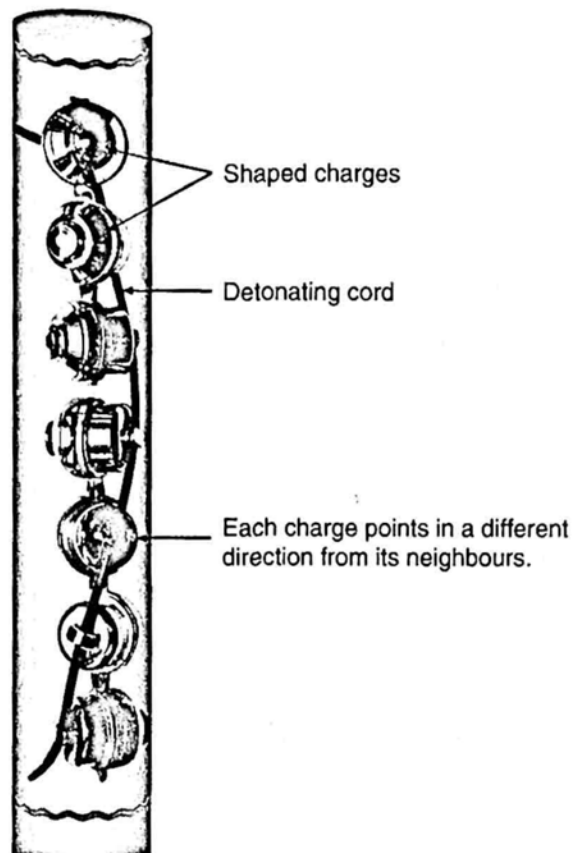


Figure 2.35 Carrier gun arrangement.

This pressure deforms the casing and crushes the cement and formation. No wellbore material is destroyed or vaporised in the process, so debris (e.g. crushed rock) is created that needs to be removed before the perforation can be effective. The perforation is complete (excepting the surging and removal of solids) within one millisecond (Grove et al., 2008).

2.3.1. Explosive selection

There are a number of different types of explosive. They vary in explosive power and temperature stability. The main explosive used is in the shaped charge. This is a secondary 'high explosive'. The explosive *detonates* at supersonic speed. Secondary explosives are also found in the detonating cord and detonator. Secondary explosives are difficult to initiate and normally require a primary explosive in the detonator to start detonating. Conversely, primary explosives may initiate by a small amount of heating (e.g. electrical resistance wire), friction, impact or static discharge. As such, they must be carefully handled and are avoided wherever possible.

Most explosives are given three-letter acronyms (TLAs) as shown in Table 2.3. The source of these acronyms is often obscure, frequently debated and not always related to the chemical. Notice the similarity of the chemical compounds in all the

Table 2.3 Explosives, acronyms and application

Abbreviation	Name	Formula	Comments
TNT	<i>Trinitrotoluene</i>	$C_6H_2(NO_2)_3CH_3$	<i>Melts at 80°C (176°F) – therefore not suitable for downhole use</i>
RDX	Research department composition X	$C_3H_6N_6O_6$	Most common downhole explosive
HMX	High molecular weight RDX	$C_4H_8N_8O_8$	Higher temperature version of RDX
HNS	Hexanitrostilbene	$C_{14}H_6N_6O_{12}$	Higher temperature stability, but reduced performance compared to HMX
PYX	Picrylaminodinitro-pyridine	$C_{17}H_7N_{11}O_{16}$	Slightly reduced penetration compared to HNS, but very high temperature stability
TATB	<i>Triaminotrinitrobenzene</i>	$C_6H_6N_6O_6$	<i>Not used on its own downhole. Common in missile systems! Very hard to detonate</i>
HTX	High-temperature explosive	Combines HNS and TATB	Various different formulations possible; better penetration than HNS, with high temperature stability

commonly used explosives. TNT is included in the table for comparison – its low melting point whilst making it very useful for creating moulded explosives limits its downhole application.

The temperature stability of the main explosives used is shown in Figure 2.36 (Economides et al., 1998a).

The stability of HTX is typically below, but close to that of HNS. As it is not a pure compound, the performance can vary with the formulation. Explosive power can also vary with the pressed density and grain size (Baird et al., 1998).

These curves are determined experimentally, with no reduction in explosive performance observed if the time-temperature limitations are obeyed. Straying beyond these limits risks the explosives degrading. This will reduce the explosive power, but also generates heat through the exothermic reaction. Possible outcomes include outgassing, low-order detonation (akin to burning) and even autodetonation. High-temperature explosives such as HNS, PYX and HTX are less likely to autodetonate, but can burn at high temperatures.

Given that the explosive power generally deteriorates with the more high-temperature stable explosives, a balance is required for the selection of the

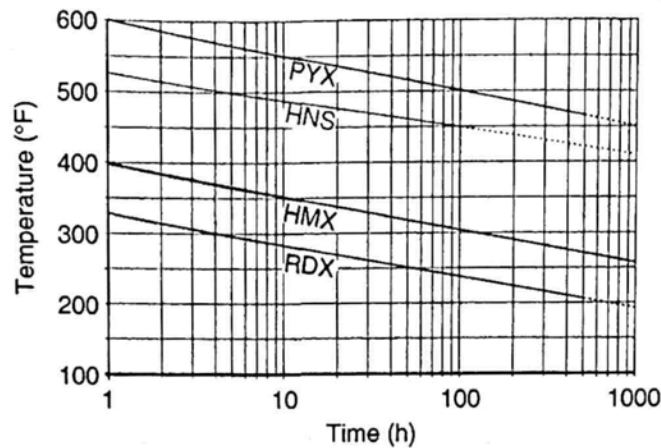


Figure 2.36 Temperature stability of perforating explosives (courtesy of M. J. Economides, L. T. Watters, and S. Dunn-Norman).

appropriate explosive. This balance will be dependent on the gun deployment method (Section 2.3.6). Guns deployed in single trip by electricline will be downhole for substantially less time than guns deployed at the base of a permanent completion. Allowance should be given for contingent operations that could slow down operations, for example bad weather.

The procurement and handling of explosives is a time-consuming operation. In most countries, necessarily stringent legislation provides strict controls on the purchasing, transport and handling of explosives. With time critical completions, early communication with the perforating company is required, even if precise details relating to the well are not yet known.

2.3.2. Perforation geometry and size

This subsection considers the geometry and size of a single perforation shot under downhole conditions. The contribution of all the perforations combined including phasing and shot density is discussed in Section 2.3.4. Clearly, a single perforation cannot be considered in isolation; however, it is important to have tools that can realistically predict the geometry of a single perforation. The overall perforation design can then be optimised based on the combined performance of many adjacent perforations.

A typical perforation hole geometry is shown in Figure 2.37.

The hole through the casing is usually free of burrs on the inside, although if the clearance from gun to casing is tight, a small burr can be created. The burr on the outside of the casing is shown in Figure 2.38, but is less of a concern.

The aim in most cased and perforated completions is to generate the maximum perforation length – deep penetrating charges. This is achieved by a relatively tight conical geometry of the shaped charge as shown with the conical liner in Figure 2.34 and the charge casing in Figure 2.39. Typical entrance hole sizes will then vary from 0.2 to 0.4 in. Occasionally, even with deep penetrating charges, the entrance