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Module 1

FUNDAMENTALS OF WELL PERFORATING

CONTENT

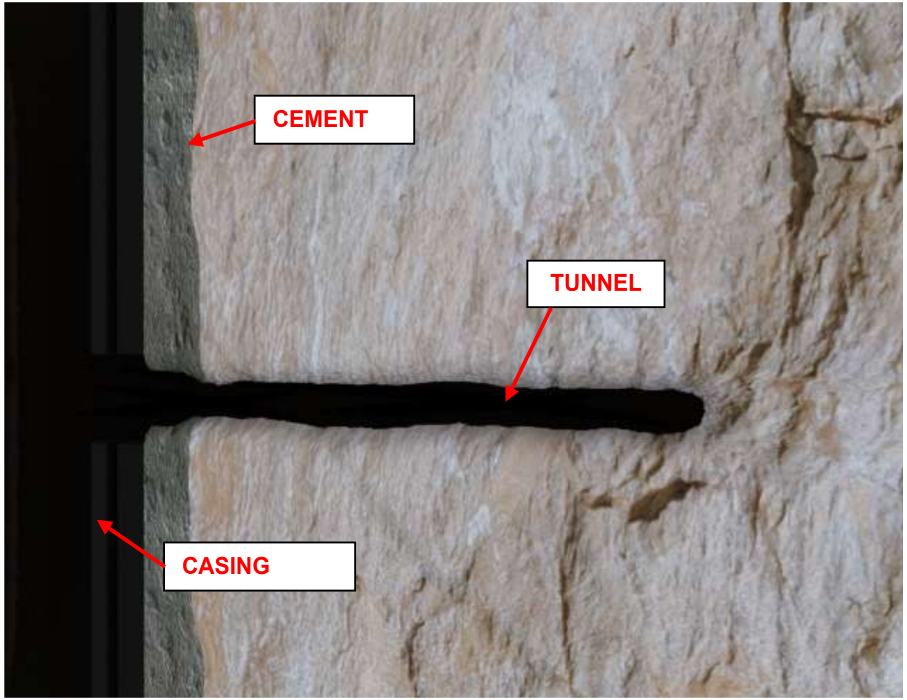
- *What is well perforating*
- *Objectives*
- *Brief history of perforating*
- *Typical types of perforating systems*
- *Advantages and disadvantages of each system*

WHAT IS WELL PERFORATING

It is a process by which a charge fired from a perforating gun, goes through the casing & cement and penetrates the reservoir rock

The penetrating effect of the charge should create an effective and efficient communication path for hydrocarbons to flow into the wellbore

Effective because the path is created and efficient because it will allow passage of fluids from the reservoir with the minimum use of energy (Pressure)



OBJECTIVES OF PERFORATING

Depending on the type of reservoir rock other objectives can be:

- The flow path can be a deep penetrating tunnel into the reservoir
- Or it can be a stable cavity instead of the tunnel
- Provide better mechanical conditions to mitigate/minimise sanding
- Flow path created must allow fluid flow with the minimum pressure drop possible
- It must be a fit for purpose process

BRIEF HISTORY OF WELL PERFORATING

- History dates from 1888 when C.E. Monroe published some observations about perforating
- First patent granted in 1926, technology was based on the use of a lead bullet fired from a gun
- Military technology was introduced in the 1930s based on charges use to perforate armour in tanks. Munitions for the “bazooka” is a typical example
- The use of explosives and shaped liners were introduced in 1966

TYPES OF PERFORATING SYSTEMS

Perforating systems can be classified according to various parameters such as type of rock or deployment method. According to deployment method we have four (4) different systems

1. Wireline conveyed – Electric cable or solid wire

2. Tubing conveyed – Completion tubing or drill pipe

3. Through tubing systems – With wireline and through the completion string

4. Coiled tubing deployed – Similar to wireline conveyed but with the circulation capacity of CT

WIRELINE PERFORATING SYSTEMS

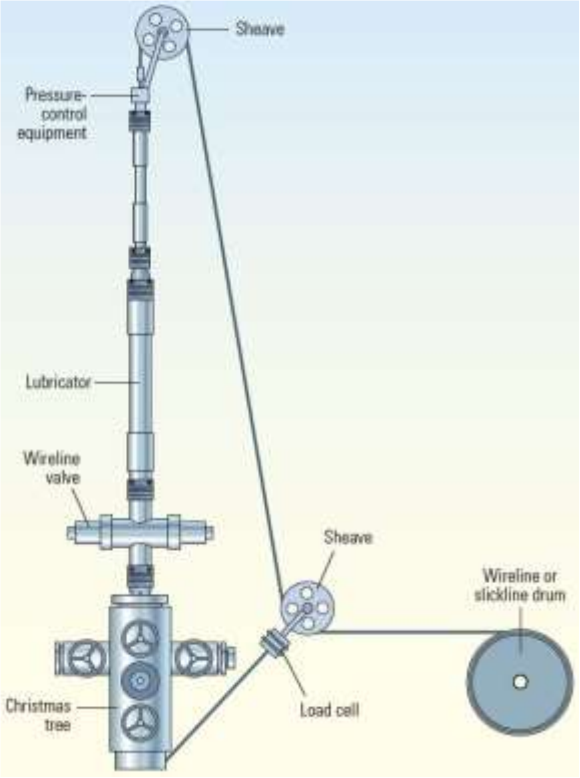
Consists of using electric wireline or solid line to convey the gun and activate the charges.

Advantages

- Accurate depth control
- Quick deployment and retrieval
- Pressure control
- Rig less

Disadvantages

- Limited length of gun due to its weight
- No circulation capability



Wireline Surface set up - Courtesy of Schlumberger

TUBING CONVEYED PERFORATING - TCP

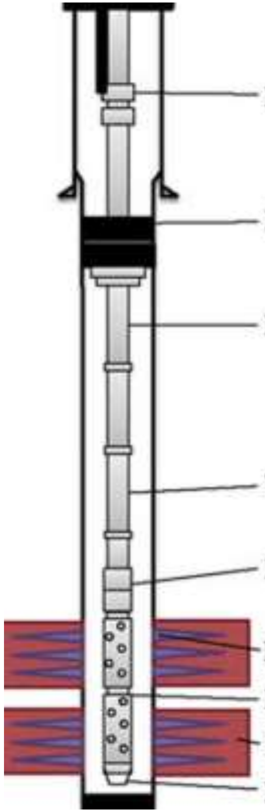
Guns are attached to the tail pipe of the completion

Advantages

- Time saving
- Maximum gun's length deployment
- Larger diameter gun possible

Disadvantages

- Rig required
- Limited depth control
- No pressure control



TCP string – After He Liu et al 2014

THRU-TUBING PERFORATING SYSTEMS

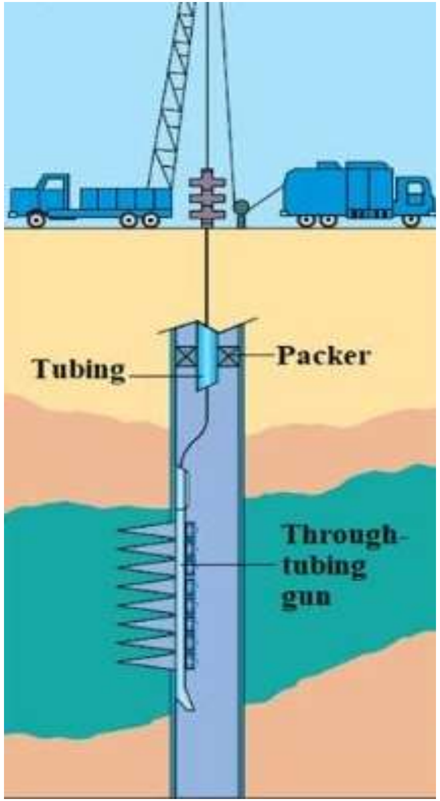
Guns are deployed through the existing completion string

Advantages

- Rig less
- Quick deployment and retrieval
- Pressure & depth control

Disadvantages

- Gun diameter is limited by the tubing size & restrictions
- Well deviation “limits” maximum depth
- Gun length limited by cable/wire resistance



Courtesy of Research Gate

COILED TUBING PERFORATING SYSTEMS

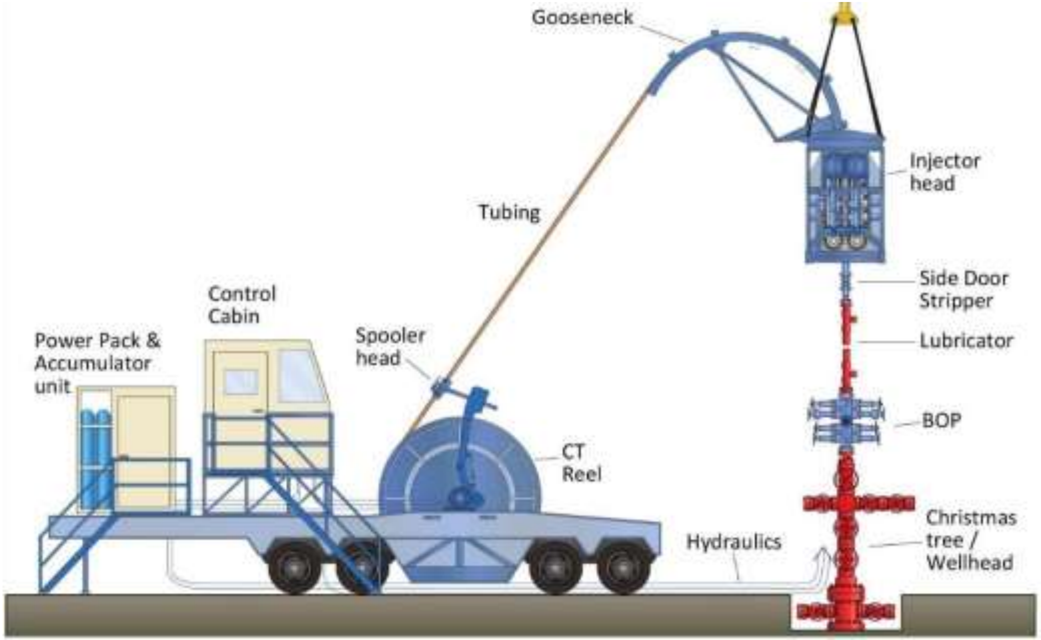
Guns deployed using coiled tubing, activation can be mechanical or via an electric cable.

Advantages

- Rig less deployment
- Possible to deploy in long horizontal wells
- Pressure control
- Fluid circulation is possible

Disadvantages

- Depth control is limited
- Costly operation



Courtesy of Research Gate

MODULE 1 - SUMMARY

Perforating is the process to establish a effective and efficient connection between the well and the reservoir. This connection takes the shape of a tunnel or a cavity depending on the type of reservoir rock being perforated

Well perforating dates from 1888, the first patent was issued in 1926 for a gun that fired a bullet to penetrate the casing, cement and reservoir rock. Explosives and shaped charges were introduced in 1966

There are four (4) types of commonly used perforating system: wireline deployed, tubing deployed, through tubing guns and coiled tubing deployed systems

Advantages and disadvantages exist for each system but in general they cover the most common requirements for most types of reservoirs and well conditions

Courtesy of Research Gate

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Module 2

SYSTEM COMPONENTS AND FUNCTIONS

CONTENT

- *Component characteristics and functions*
- *Wireline (Casing) guns*
- *Completion deployed guns*
- *Thru-tubing systems*
- *Coiled Tubing systems*

COMPONENT'S CHARACTERISTICS

In general terms the main components (Equipment) used in well perforating can be divided by function, there are four (4) as follows:

1. ***Control unit*** – Guns deployed in wireline and coiled tubing is similar to standard equipment. It is not required for tubing/drill pipe deployed guns

2. ***Surface equipment*** – These are components such as the winch/Reel, pressure control (BOPs, stuffing boxes, riser) that are required for deployment at surface

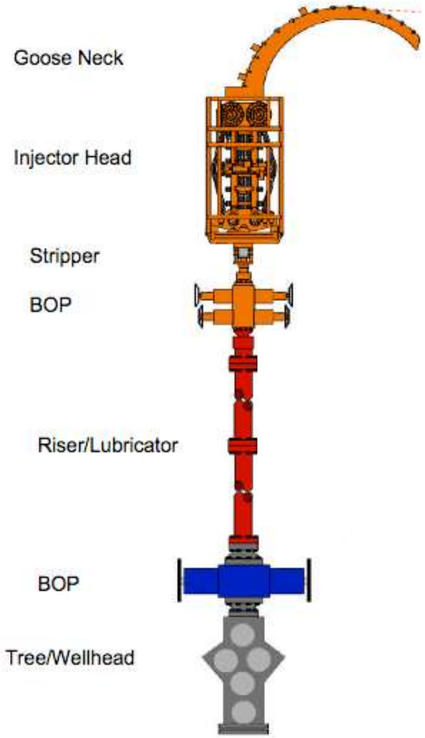
3. ***Deployment system*** – Electric wireline, coiled tubing and steel wire are the most common means of gun deployment. Tubing/DP for TCP systems

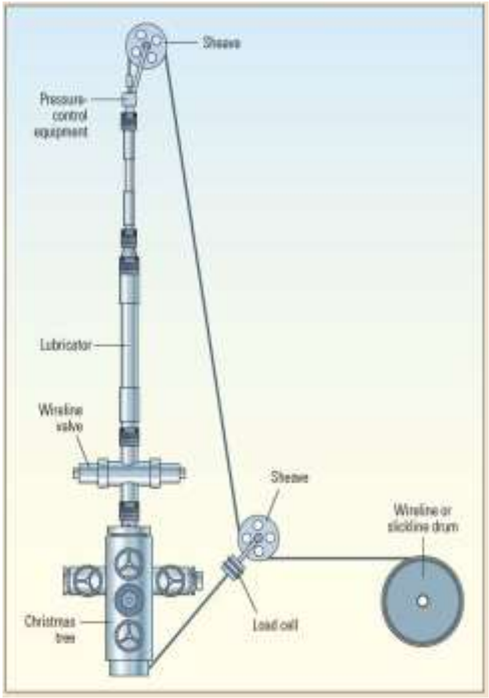
4. ***Perforating gun*** – Carrier with shaped charges and accessories, depending on the type selected and deployment method

COMPONENT'S CHARACTERISTICS (Continued)

Coiled tubing and wireline surface set up composed of:

- Pressure control equipment, BOPs, stripper
- Riser/Lubricator
- Winch (Wireline)
- Injector head
- Goose neck

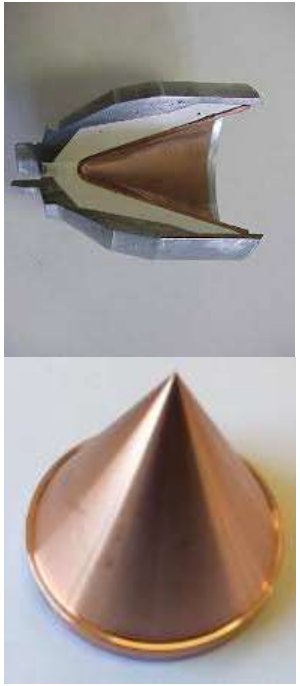




COMPONENT'S CHARACTERISTICS (Continued)

Gun system and components will depend on the deployment method selected

TCP Gun Carrier and charges
(Courtesy of The Expro Group)



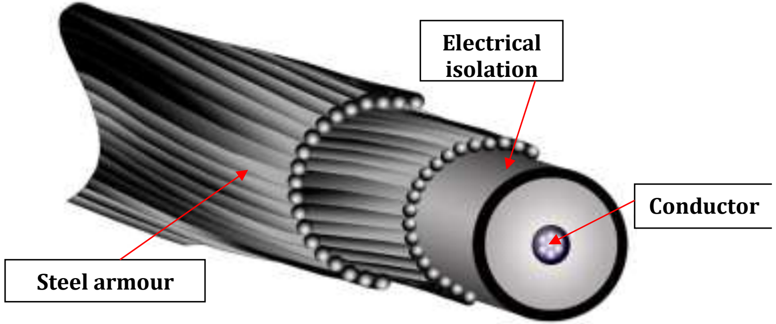
Charge and Shaped liner
(Courtesy of Springer)

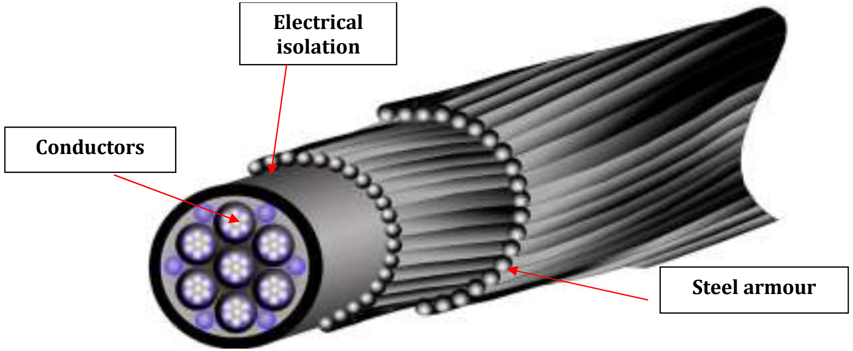
Gun assembly
https://pmrpressrelease.com/perforating

COMPONENT'S CHARACTERISTICS (Continued)

Cable and wireline specifications

CHARACTERISTICS	ELECTRICAL CABLE	STEEL WIRE (slickline)
Types	Mono conductor, hepta-cable	Braided and solid line
Diameter range (Inches)	7/34"	[0.092 – 0.108]
Weight (Lbs/ft)	-	[0.02 – 0.028]
Tensile load (lbsf)	-	[675 – 1800]
Chemical resistance	Limited by rubber elements	Affected by H_2S
Pressure containment	Stuffing box and connector seal	Stuffing box
Operational Limitations	Well geometry, gun length/weight, wellbore fluids	Well deviation, tensile load, tubing size, cycling
Depth control	Very good	Good
Main problems	Conductor damage, kinks	Fatigue, mechanical damage
Max. Deviation (degrees)	< 60 ° nominal, extended with accessories (rollers, wt bars)	



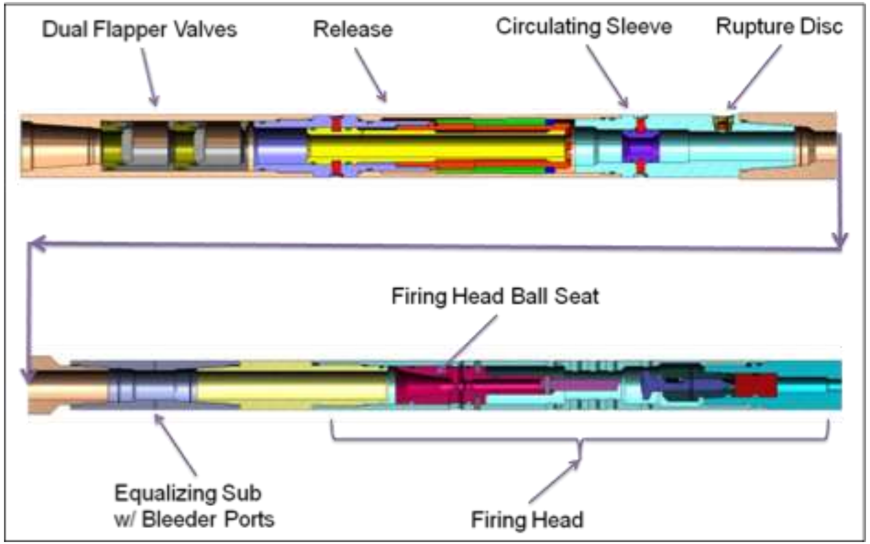


COMPONENT'S CHARACTERISTICS (Continued)

Well perforating using Coiled Tubing takes advantage of two (2) key features of the technology:

1. Ability to convey and retrieve heavier/longer gun assembly

2. Fluid circulation from surface allows well control, stimulation and fluid treatments to be carried out

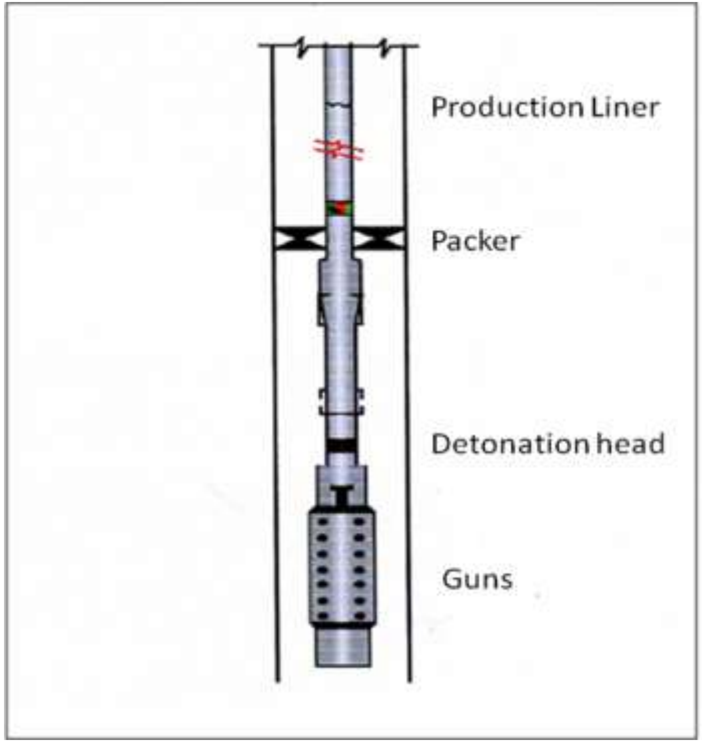


CT – Perforating gun interface
(Courtesy of Halliburton)

COMPONENT'S CHARACTERISTICS (Continued)

Tubing conveyed perforating - TCP

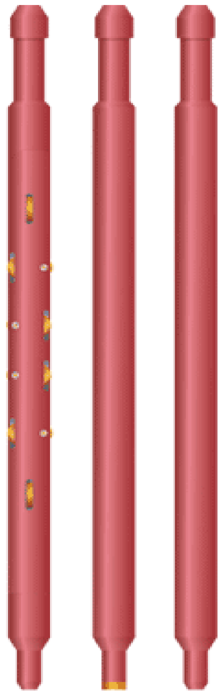
- Deployed w/completion as the deployment system
- Large (Long) size guns & charges are possible
- Accessories include firing and release mechanisms, circulating subs…



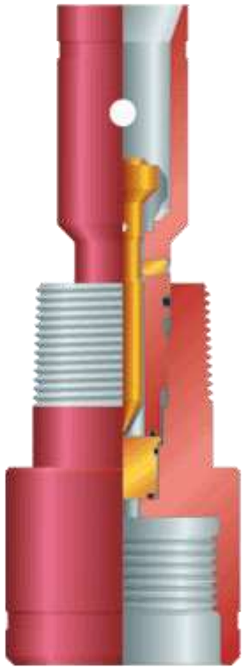
COMPONENT'S CHARACTERISTICS (Continued)

Types of firing mechanisms for TCP

- Mechanical (Drop bars)
- Hydraulic (Fluid pressure)
- Electrical (Cable)

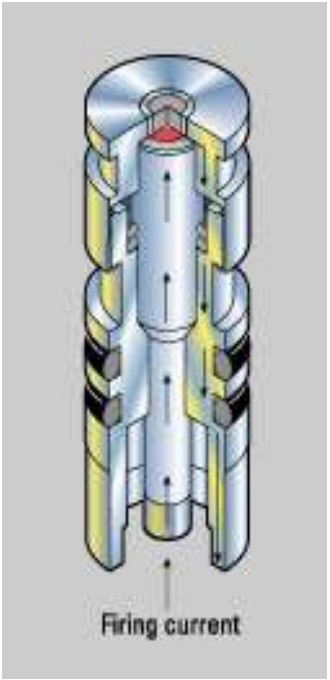


Drop Bars



Mechanical F.H

Hydraulic FH



MODULE 2 – SUMMARY

Equipment characteristics vary among perforating systems depending on the deployment method and supplier

Four (4) main components are common: Control unit, surface equipment, deployment system and perforating gun. Not required in all methods

Gun systems are very similar for all four (4) techniques however, obvious differences remain such as between Coiled tubing and through tubing perforating.

Advantages and disadvantages exist for each system but in general they cover the most common requirements for most types of reservoirs and well conditions

Systems that provide accurate pressure and depth control, rapid deployment and retrieval are very common

MODULE 2 – SUMMARY (Continued)

Variations between systems include mostly accessories that improve compatibility and functionality (i.e. firing heads, connectors)

The ability to be able to circulate fluids is very useful making CT perforating a suitable method

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Module 3

EXPLOSIVES AND CHARGES

CONTENT

- *The perforating process*
- *Type of explosives, uses and functions*
- *Common type of charges*
- *Propellants*

THE PERFORATING PROCESS

It can be divided into four (4) main steps

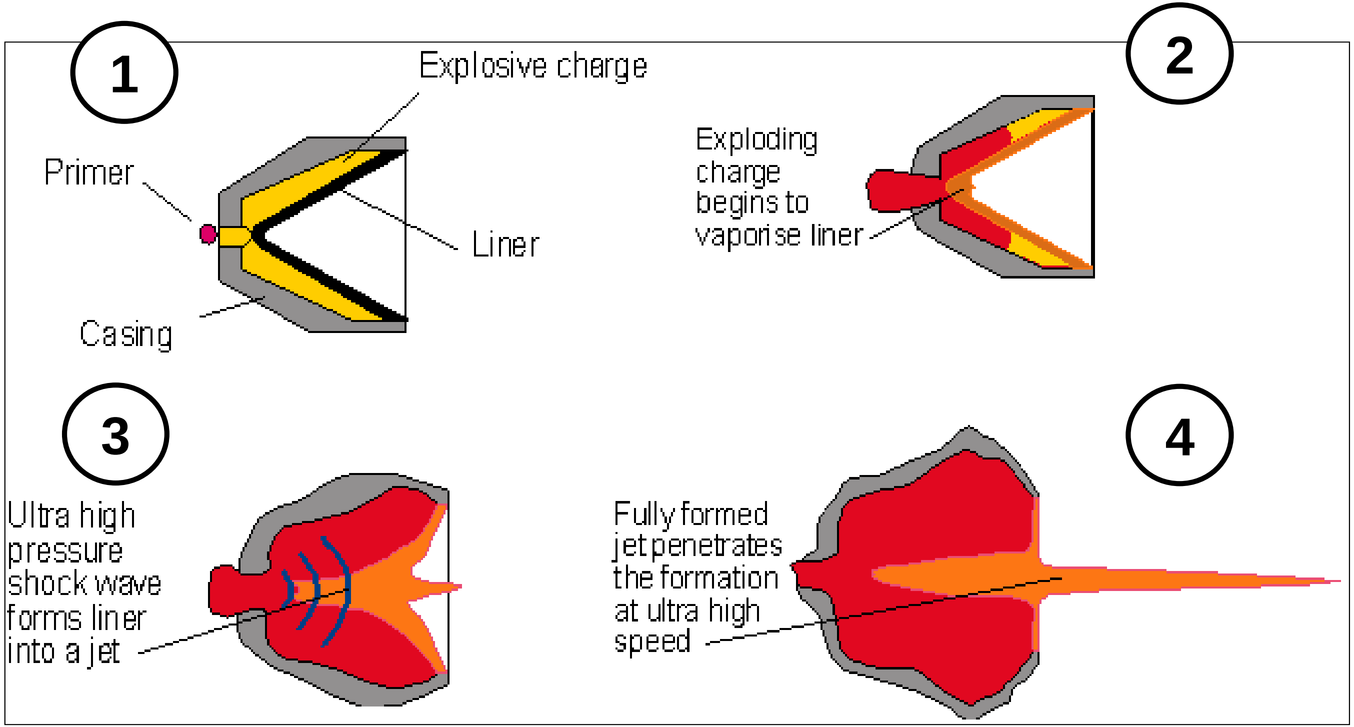
1. ***Deployment and positioning*** – Gun needs to be lowered to the required depth, this needs to be verified

2. ***Activating the gun*** – Depending on the method of deployment, either Mechanical, hydraulic or electric ignition of the primer and charge will occur

3. ***Fluidizing of the liner*** – Fluidization of the liner into a “jet” will occur as a result of the high pressures and temperatures generated by the ignition of the charges

4. ***Expelling of the jet*** – a high pressure/temperature fluidized liner is expelled at very high speed to penetrate the casing/cement and into the reservoir rock

THE PERFORATING PROCESS (Continued)



TYPE OF EXPLOSIVES, USES AND FUNCTIONS

CHARACTERISTICS	TYPE	
	HIGH EXPLOSIVES	LOW EXPLOSIVES
Type	Primary & secondary	-
Method of initiation	Primary by ignition and secondary by detonator	By ignition
Time of conversion	Microseconds	Milliseconds
Velocity of flame front	2 – 10 Km/sec	0.5 – 1.6 Km/sec
Pressures generated	50000 – 4000000 psi	< 50000 psi
Common uses	Demolition, blasting, shaped charges	Propellant, blasting, bullet guns

TYPE OF EXPLOSIVES, USES AND FUNCTIONS (Continued)

Explosive specifications

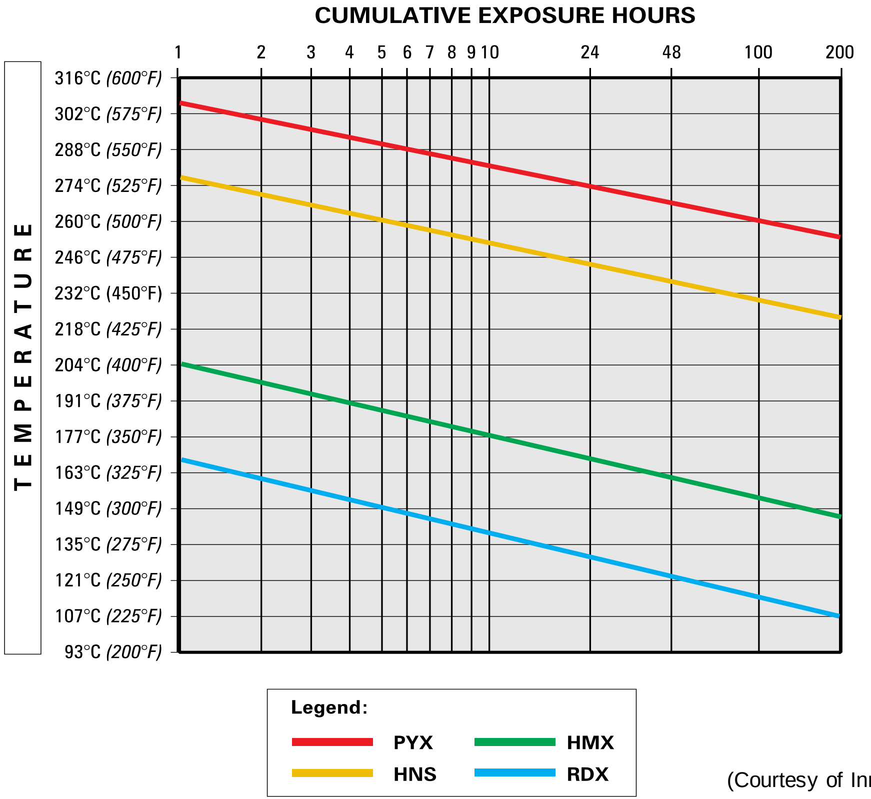
PROPERTY	TYPE					
	PRIMARY		SECONDARY			
Name	Lead Azide	Tacot	HNS	RDX	PSF	HMX
Chemical formulations	PbN_6	$C_{12}H_8O_{12}N_4$	$C_2H_2N_6O_{12}$	$C_6H_6N_6$	SN_6O_{14}	$C_4H_8N_8O_8$
Temperature limit [°C]	329	378	320	180	307	327
Density [kg/m^3]	-	-	1740	1820	-	1900
Detonation velocity [m/s]	-	-	7000	8400	-	9124
Remarks			For HT charges	Most common	For HT charges	>T than RDX

TYPE OF EXPLOSIVES, USES AND FUNCTIONS (Continued)

Explosives can degrade in time if exposed to temperatures above their limits

Choice of charge must consider operational time for the particular method selected

In some cases, guns are left in the wellbore without activating for many months.



(Courtesy of Innicor)

API 19B TEST RECOMMENDATIONS

EQUIPMENT/ CONDITION	API RECOMMENDATION
Perforating system	Standard field gun with charges of particular phasing, shot density, continuously loaded
Charge selection	RDX or PETN samples from a minimum of 1000 units run
	A minimum run of 300 charges for HT explosives
Charge storage	Conventional manufacturer's package, a minimum of 4 weeks aging prior to testing, selected from closed containers
Multi directional guns	A continuously loaded gun to provide a minimum 12 shots or 1 foot
Uni-directional guns (0° phasing)	Must be tested in two positions, all shots fired with maximum and minimum gun clearance. A minimum of 8 shots ofr each position
Test fluid	Water
Test QA/QC	For a test to be valid it is required that the average depth of penetration does not reaches within 3 inches from the outer steel vessel
	Shots that are 12" from the top or 6" from bottom of the target are not to be counted for penetration results computation
Data Acquisition	Three parameters are measured, Total depth of penetration, entry hole diameter and burr height
Reporting results	Use API Form 19B section 1

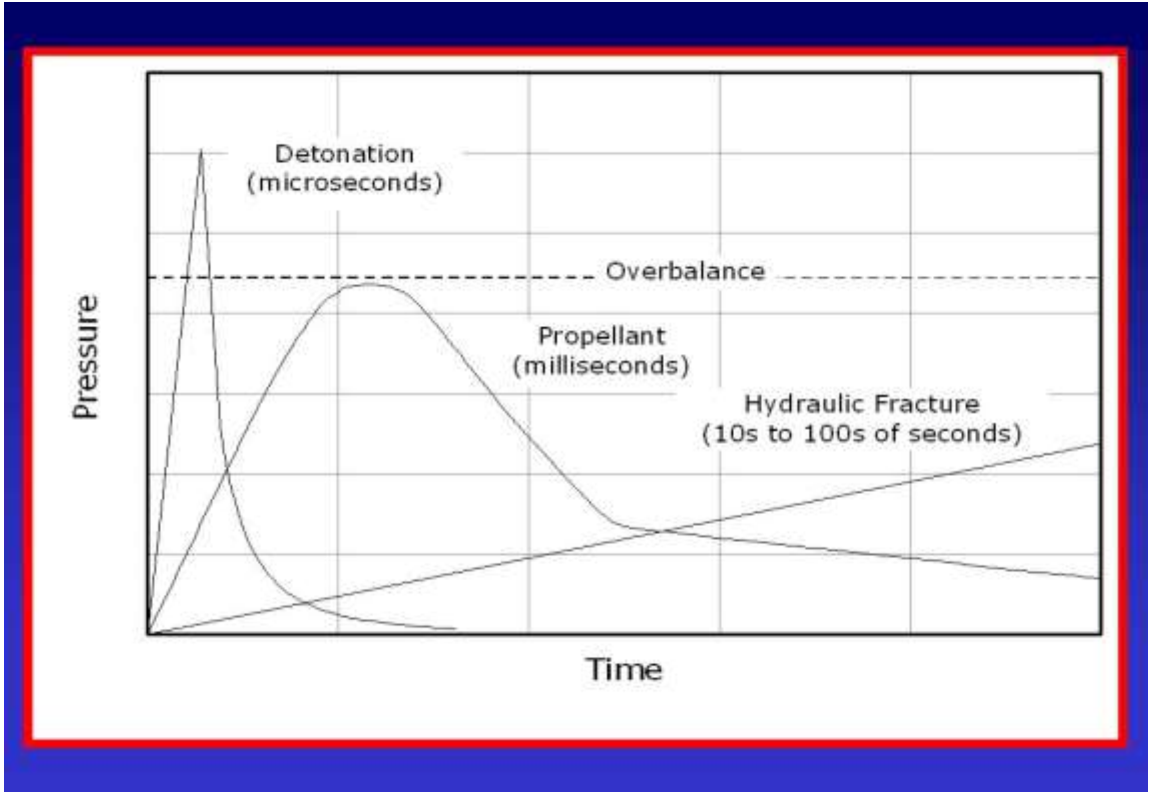
PROPELLANTS

This method relays on the placement of a propellant sleeve outside a conventional gun's carrier.

- The actual firing of the gun ignites the sleeve
- Pressure generated can reach 30000 psi in intervals of 1 to 10000 microseconds
- High-pressure waves follows the gun's shot and creates fractures in the rock Propellants are low power explosives
- Various service providers supply the technology

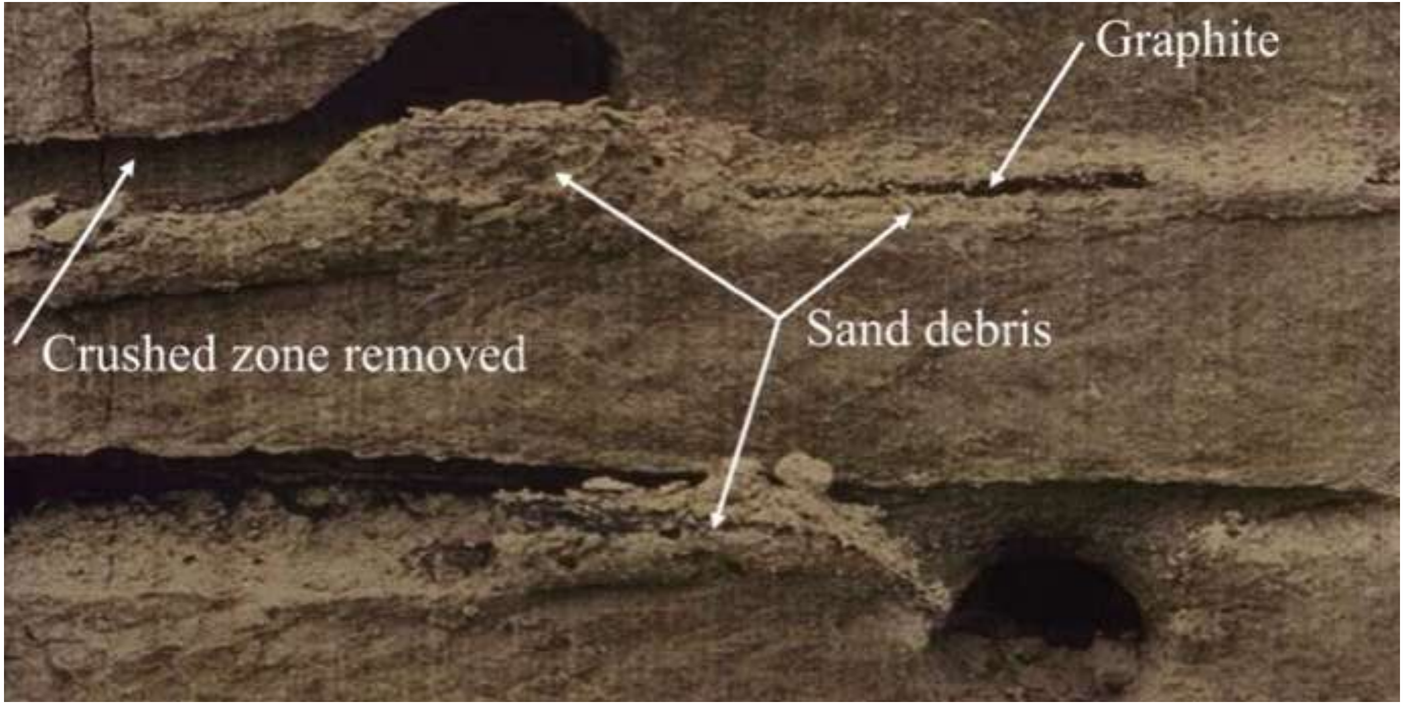
(StimGun Courtesy of Owen Oil Tools)

PROPELLANTS (Continued)



(Courtesy of Slide Player)

RESULTING PERFORATIONS (Test samples)



(Courtesy of Schlumberger)

MODULE 3 – SUMMARY

Four (4) typical steps can be used to represent the perforating process: Deployment/positioning, gun activation, liner's fluidizing and expelling

Two (2) main type of explosives are utilised in perforating; low and high explosives, some used as igniters and some used as charges

RDX, HMX and HNS are the most common type of explosive charges, the main difference is the temperature rating

API RP 19b is a reference for the development of procedures and specifications for testing charges

Propellants are also use along with perforating guns for enhanced well performance, an sleeve (Propellant) is placed around the perforating gun

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Module 4

PERFORATING OPERATIONS

CONTENT

- *Steps in the design and execution of perforating operations*
- *Design phase*
- *Gun preparation*
- *Deployment of the BHA*
- *Gun activation*

STEPS IN THE DESIGN AND EXECUTION OF PERFORATING OPERATIONS

PERFORATING PROCESS

DESIGN STAGE

Development of the technical and operational specifications

JOB PREPARATION

Equipment testing, QA/QC and verification of original design, planning & contingency

GUN DEPLOYMENT

Equipment set up at the well site, safety checks, well handover and lowering the gun system to firing depth

ACTIVATION

Gun positioning, change in operational conditions and actual firing of the guns at reservoir level

EVALUATION

Initial well flow, well test and skin determination

DESIGN STAGE

It includes all the technical aspects related to perforating such as gun and charge and method selection as well as operational planning and Quality Control.

1. Review of reservoir properties and well characteristics
2. Type of charges and its characteristics(weight, temperature ratings…)
3. Deployment method, preliminary operational procedures, well conditions and description of the equipment to be used
4. Predicted results, perforation’s length, Inflow and productivity estimations (including potential damage/skin)

The resulting design program will then be used as a working document that will allow initial input from other areas/department involved/contributing.

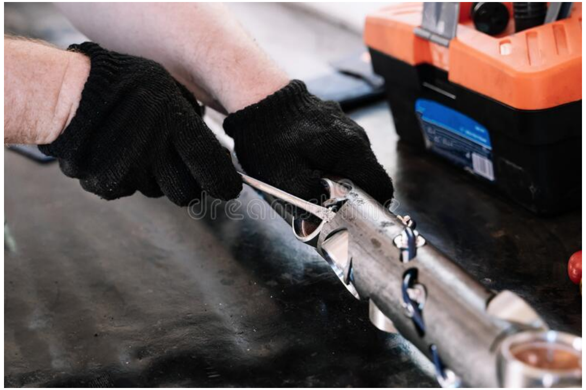
JOB PREPARATION

RESPONSIBLE	TASK	REMARKS
OPERATOR	Service supplier selection	Service company QA/QC review
	Inspection and testing	Visual inspection of yard/shop testing
	Rig and site evaluation	QA/QC review for perforating operations
	Accessories and support equipment selection	Pumping, tanks, WT and nitrogen equipment as required
	Logistical and administrative	Contracts, rig's mob/demob, operational planning and well site preparation

RESPONSIBLE	TASK	REMARKS
CONTRACTOR	Verification of equipment availability	Well control, gun system, charges and control unit available and in working order
	Certification and permits	Charge certs, pressure test charts and records of all equipment to be used
	Site inspection prior to operation	Visual inspection of well site in order to plan equipment layout, safety working requirements
	Safety and Planning	To be carried out with the customer and other contractors, HAZOPS
	Logistical arrangements	Order third party components and equipment, timings and personnel selection

GUN PREPARATION

- Transportation from base to location
- System preparation and assembly on site
- Operational interaction and integration with current site operations
- Breaking and restoring well integrity to insert system into the well
- Lowering the gun to depth



(Courtesy of Dreamtime

GUN DEPLOYMENT

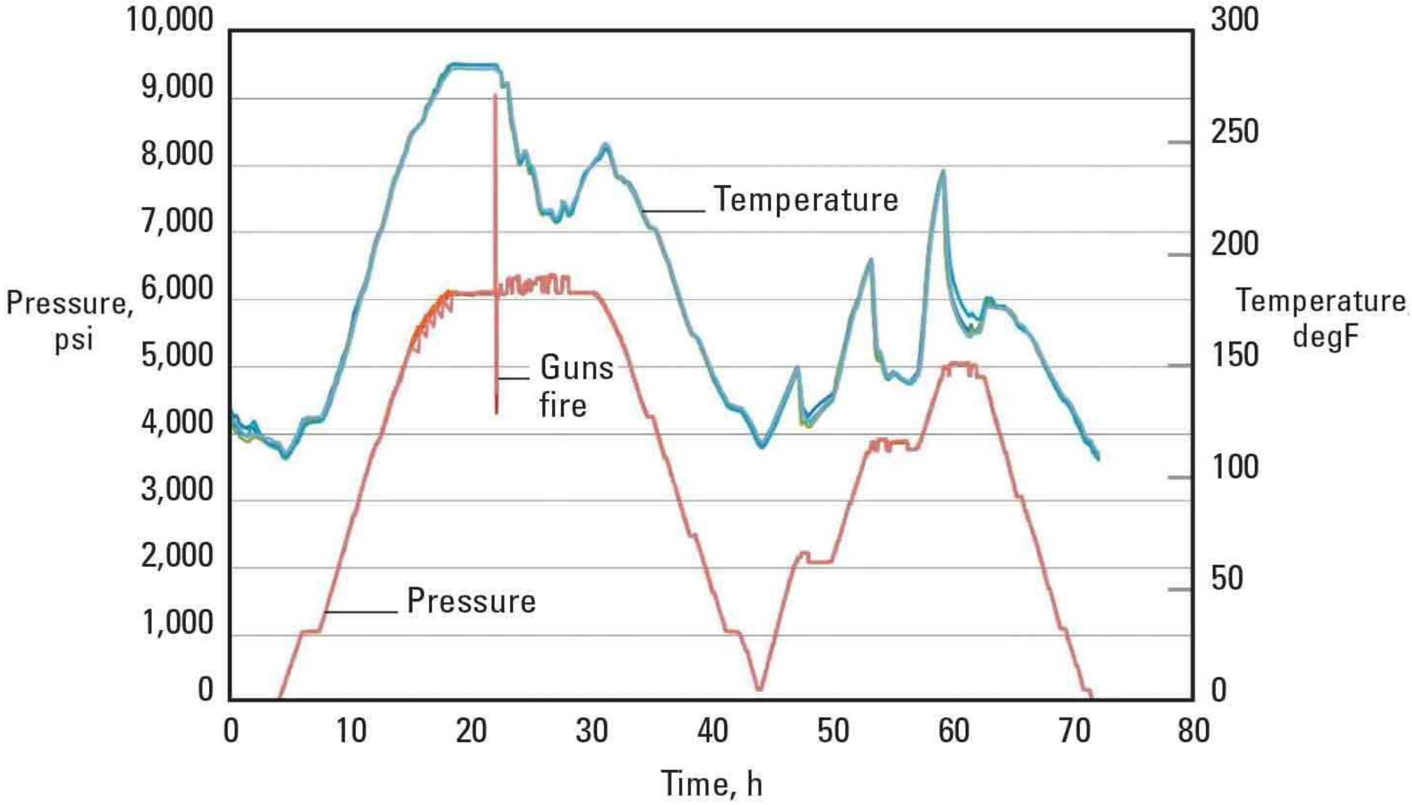
- Process depends on method selected (TCP, WL, CT..)
- Pressure control requirements
- Rigless for CT/WL

(Courtesy of Innicor)

GUN ACTIVATION

- Confirmation of mechanical status of the gun and accessories downhole
- Positive confirmation of gun's positioning and orientation
- Activation and confirmation of firing
- Gun and accessories retrieval or disposal
- Positive indication establishing inflow from the reservoir via production information flow/pressure/temperature

GUN ACTIVATION (Continued)



JOB EVALUATION

LOCATION	WHAT TO EVALUATE	HOW
Well site	Confirmation of gun location via CCL(Sonic) or GR(Radioactive)	Using pup joint placed on casing/liner
		Using radioactive marker positioned in the casing
	Confirmation of firing on control unit screen	Being present during actual firing operation
	Identification of positive reservoir-wellbore communication being established immediately after firing	THP or surface pressure increase, flow of well fluids after activation
	Visual inspection of gun after retrieved from well	Counting each and all of the charges to ensure that were fired
	Quantification of flow/pressure contribution throughout the reservoir	Running production logging tools PLTs
Off site	Inspecting for any particular problems encountered	Visual inspection of system redress and servicing at the shop
	Well productivity and performance	Carry out NODAL analysis to determine actual well performance
	Operational performance	Review detailed reports to identify areas for further improvements
	Determination of detailed gun performance	Using analytical models to determine shot penetration and flow

MODULE 4 – SUMMARY

Perforating includes at least four (4) steps: design and preparation, gun preparation, gun deployment and activation, job evaluation

The operator participates in the selection and specification of the gun system and the contractor on the detailed preparation, assembly, deployment/retrieval and activation of the system

QA/QC, testing and verification is perhaps the most important activities of this operation

Type of method selected, reservoir properties and well characteristics will influence the specifications of the gun specifications and the operational procedures

Performance evaluation is based on final production/impairment results

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Module 5

RESERVOIR MECHANICAL CONDITIONS

CONTENT

- *Influence of reservoir mechanical conditions on perforating performance*
- *In-situ field stresses*
- *Rock mechanical properties*
- *Pore pressure*
- *Reservoir temperature*

INFLUENCE OF RESERVOIR MECHANICAL PROPERTIES

Reservoir mechanical conditions and properties define and limit perforation performance, these properties are:

- In-situ stresses
- Rock mechanical properties (Strength and deformation)
- Pore pressure

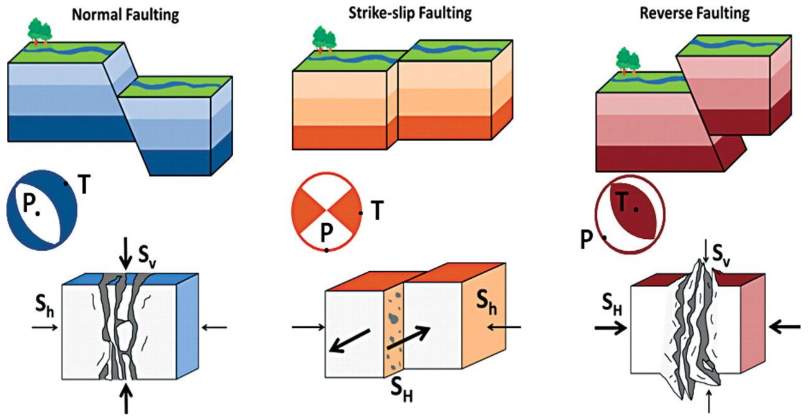
As a result, the final shape, length and productivity of a perforation tunnel is defined mainly by these conditions and properties

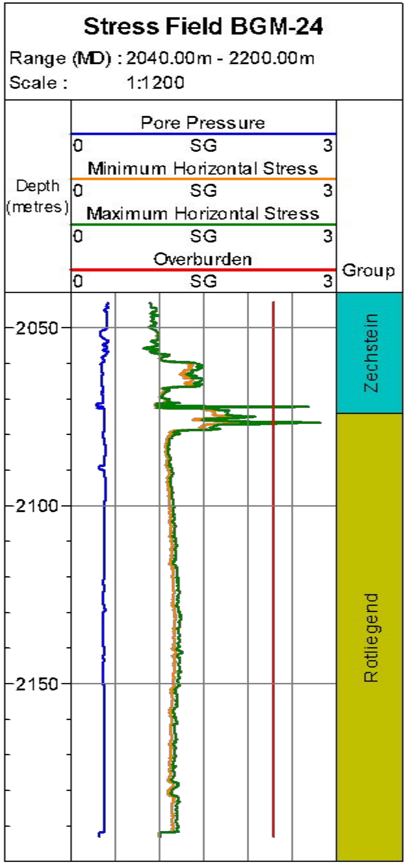
The type of reservoir (in mechanical terms) be it competent or unconsolidated required adequate design of the perforating program based on these conditions and properties

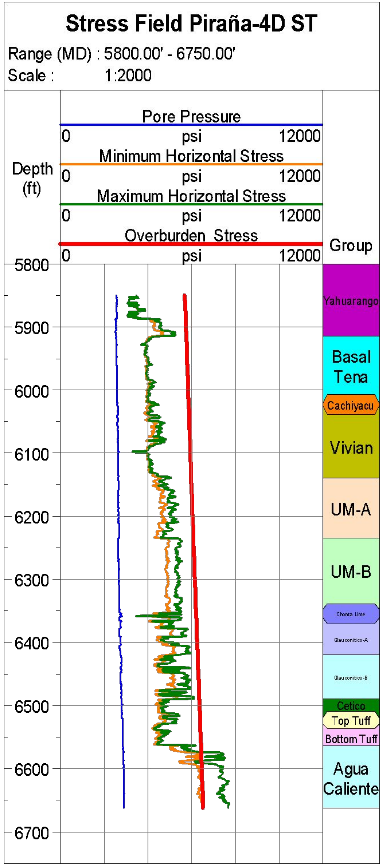
IN-SITU STRESSES

In-situ stresses are the loading acting on the reservoir represented by the main principal stresses σ_v, σ_H and σ_h

Perforating charges must overcome these stresses





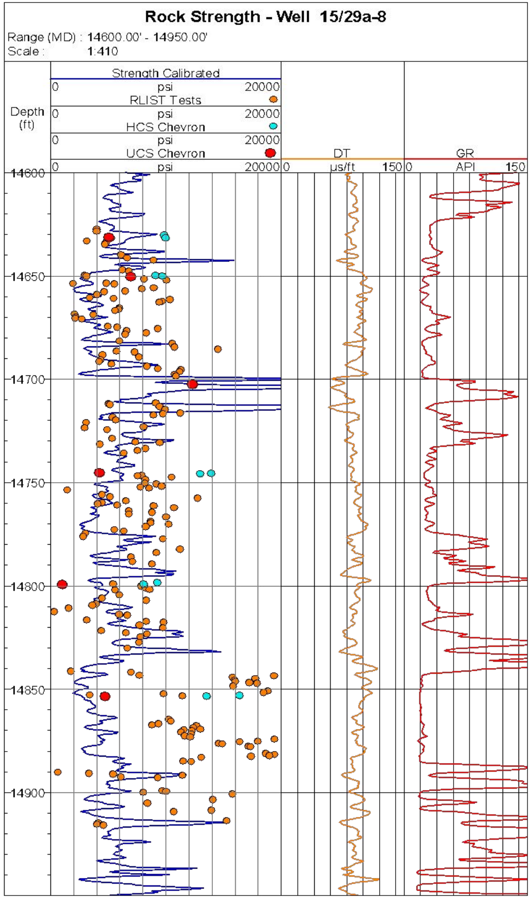


ROCK MECHANICAL PROPERTIES - Strength

These are properties that represent rock strength and deformation behaviour. They can be static and dynamic properties

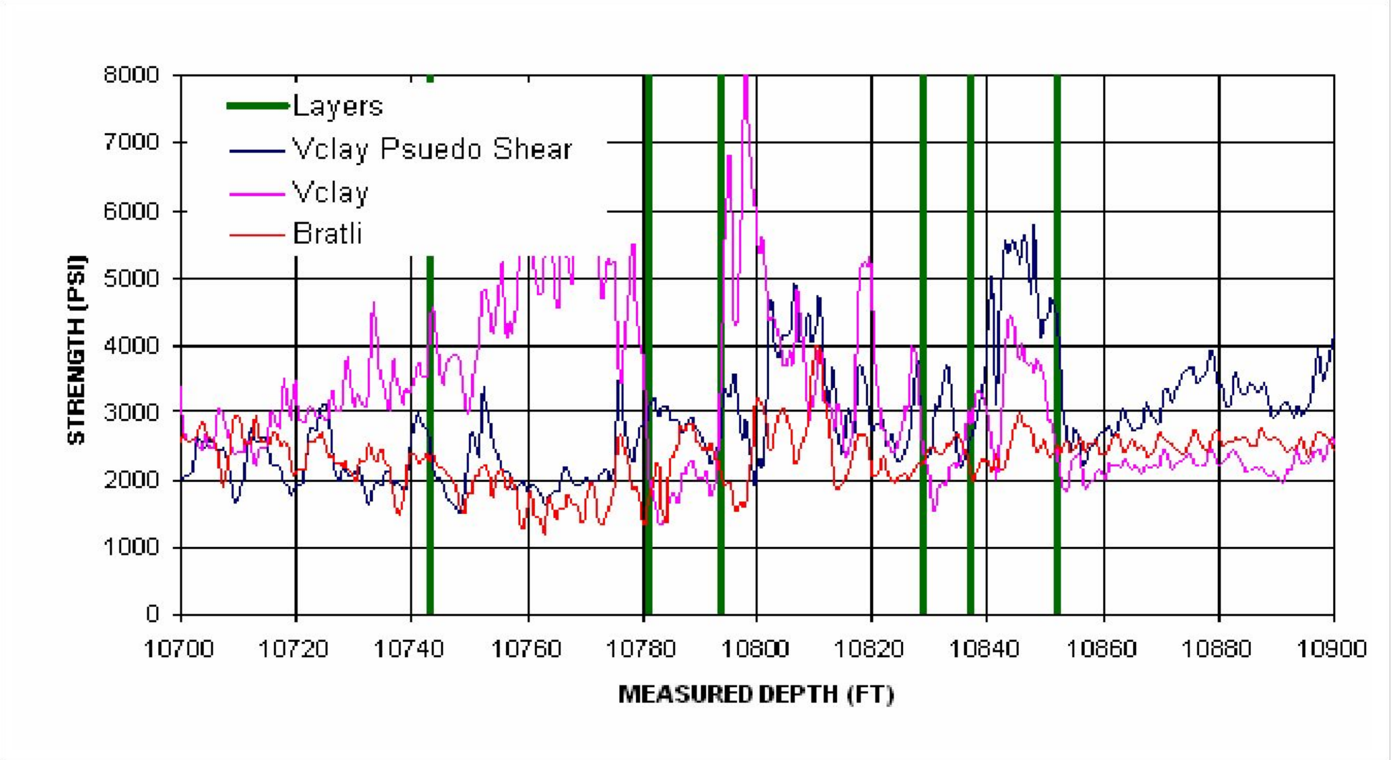
Courtesy of PDVSA Intevep

Courtesy of IESL



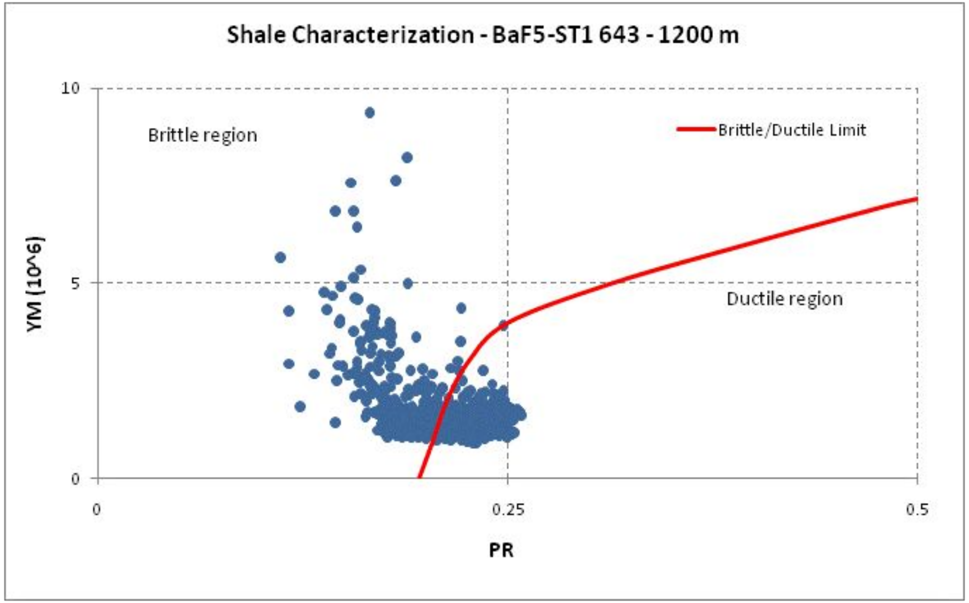
ROCK MECHANICAL PROPERTIES – Strength (Continued)

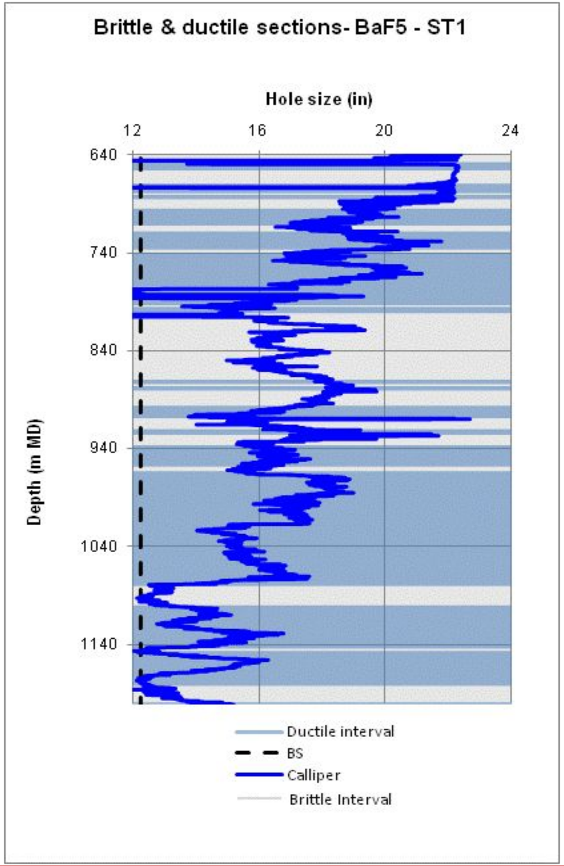
Estimated using correlations available and calibrated using measurements



ROCK MECHANICAL PROPERTIES - Deformation

Deformation is represented by Young modulus and Poisson's ratio





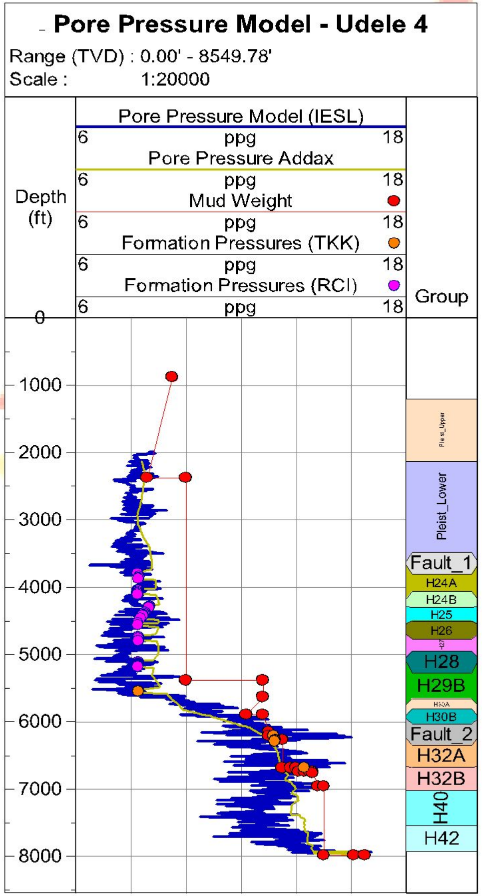
PORE PRESSURE

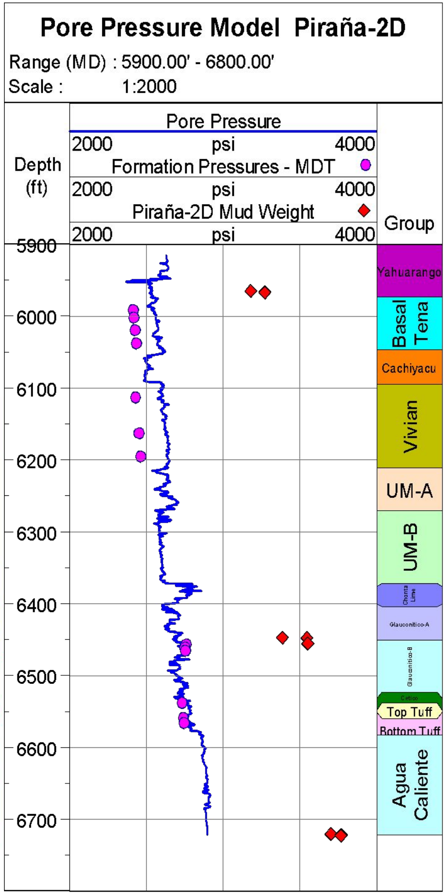
Pore pressure helps the rock framework to cope with the loads (Stresses)

Load transmission through grain-to-grain contact points increases with the decrease of pore pressure

Modelling of pore pressure is calibrated with measurements such as pressure surveys, MDT, RFT

Pore pressure acts against the perforation charge





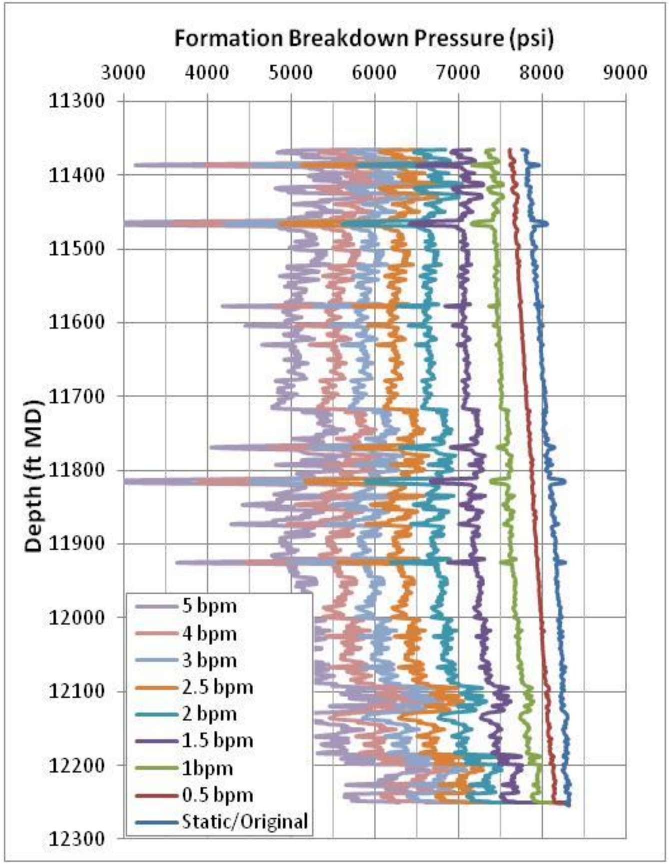
RESERVOIR TEMPERATURE

Reservoir temperature influence the mechanical properties of the reservoir

With temperature changes (From circulation etc.) the magnitude of properties such as:

- fracturing pressure,
- compressive strength and
- in-situ stresses

will vary, this effect can be used to enhance perforation performance in certain scenarios

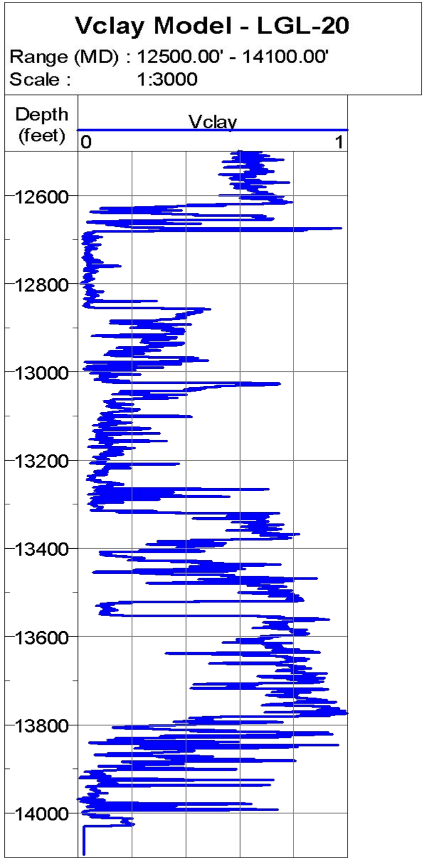


OTHER RESERVOIR PROPERTIES

Mineralogy and petrophysical properties of a reservoir can affect the mechanical behaviour of the rock during perforating by:

- Defining the manner in which deformation takes place
- Increasing or decreasing compressive strength hence the length of the perforated tunnel
- Determining the condition of the perforated tunnel and its inflow capacity

These properties are the amount of clay present in the reservoir matrix, grain size, porosity and permeability



MODULE 5 – SUMMARY

Mechanical and petrophysical properties and conditions can affect perforating performance.

Stresses, strength and pore pressure oppose the forces generated by the shot, Young modulus and Poisson’s ratio define how the rock deforms during perforating

Pore pressure helps the rock framework to deal with the loading (Stresses, drawdown), a decrease in pore pressure might lead to an increase in loads on the rock

Increases/decreases in reservoir temperature modify strength/deformation properties

Other geometrical and petrophysical properties such as grain size, clay content and porosity can affect perforation performance

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Module 6

PERFORATION DESIGN

CONTENT

- *Gun selection considerations*
- *Gun size and length*
- *Phasing and shot density*
- *Charge type and size*
- *Perforation penetration*

PERFORATING METHOD SELECTION CONSIDERATIONS

Method selection criteria is driven by the following parameters

1. Well conditions and geometry – Casing/tubing sizes, deviation, orientation, location (offshore, onshore, swamp..), well and reservoir fluids

2. Reservoir mechanical properties – Strong or weak reservoir rock

3. Completion design requirements – Fracturing, sand control, water injection

4. Pore pressures – Requirements for pressure control

5. Availability of services – Supplier's capabilities and track record

6. Cost – Rig versus rigless operations

GUN SELECTION

To certain extent gun selection depends on the perforating method however, there a number of parameters that need to be specified as follows:

- Gun size (O.D.) and length
- Shot density and phasing
- Charge size (weight of explosives) and temperature range
- Charge entry hole and penetration
- Pressure conditions (Over or underbalance)

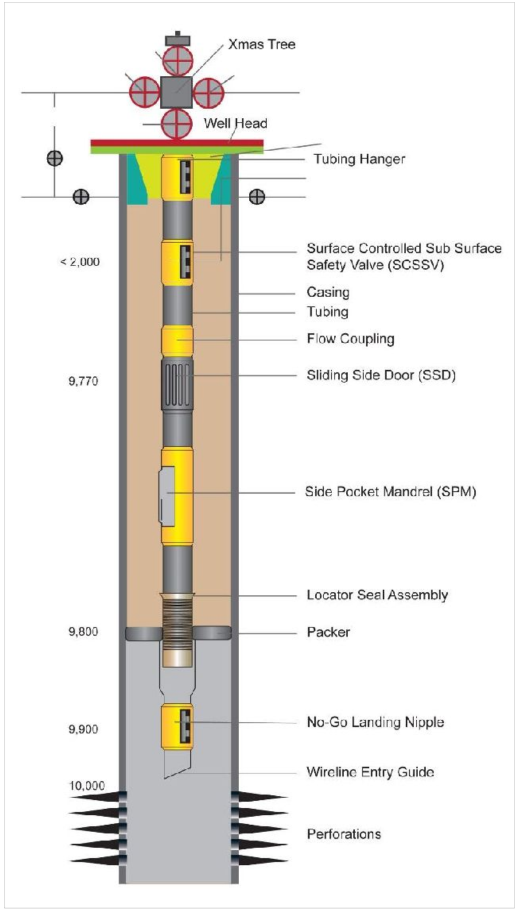
GUN SIZE AND LENGTH

Well constraints such as casing/tubing size and restrictions (Nipples, I.D. changes) will dictate the O.D. of the gun

Other considerations such as deviation and dog-leg severity also influence the selection of the gun's O.D.

Gun length on the other hand is determined by the length of the interval to be perforated and the perforating method

Wireline (E-Line or wire) can carry limited amounts of weight (< 30 ft of guns). TCP or CT deployed guns do not have a length's limitation



SHOT DENSITY AND PHASING

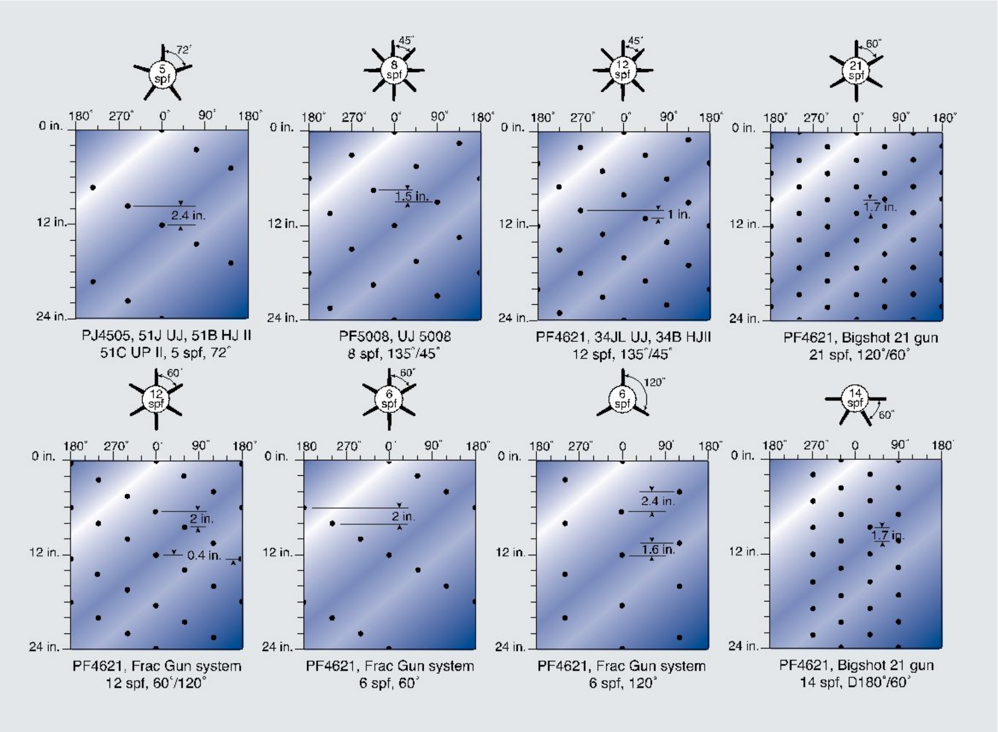
Shots per foot and phasing (Charge orientation) are selected to provide large inflow, low pressure drawdown and perforation's stability.

- Large inflow and PI requires higher flow area = high shot density
- It will also benefit from larger entry holes
- Common shot density are 4, 8, 10 & 12 spf

Phasing while related to inflow is for some applications to give mechanical stability to the tunnels. Applications such as sand production can benefit from oriented perforations

Typical orientations are 0°,60°,90°,120° and 180°. 0°and 180° are used for oriented perforations

SHOT DENSITY AND PHASING (Continued)



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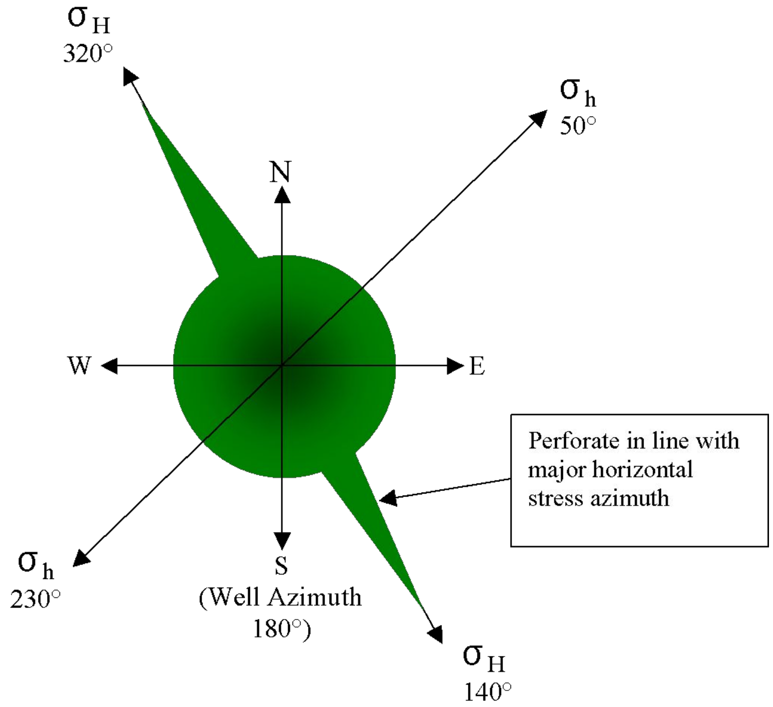

CHARGE SIZE AND TEMPERATURE LIMITATIONS

Suppliers specify charge performance results and use the API Recommended Practices as a reference

- Example table illustrates the reported charge performance for a 5” HSD gun
- Weight is presented in grams of explosives
- Temperature ranges provided for RDX, HNS & HMX chages

Charge	Explosive type, maximum weight (g)	Shots per foot, phasing (°)	Entrance hole [†] (in.)	Burr avg /max (in.)	Area open to flow ($in.^2/ft$)	Penetration [†] (in.)	Temperature [‡] (°F)	Target strength (psi)	Test date
34B HyperJet II	RDX, 21.7	12, 135/45	0.39	0.10		19.8	340/240	7020	07-95
34B HyperJet II	HMX, 21.7	12, 135/45	0.39	0.09		22.8	400/300	5816	12-92
34JL UltraJet	HMX, 22.7	12, 135/45	TBD			TBD	400/300		
34JL UltraJet	HTX, 21.0	12, 135/45	TBD			TBD	500/460		
UltraJet 5008	RDX, 25.0	8, 135/45	0.54	0.11/0.22		20.2	340/240	6629	4-00
HyperJet 4505	RDX, 38.8	5, 72	0.57[§]			37.0[§]	340/240		
UltraJet 4505	HMX, 38.8	5, 72	0.46[§]			46.8[§]	400/300		
PowerJet 4505	HMX, 38.8	5, 72	TBD			TBD	400/300		
51J UltraJet	HNS, 38.5	5, 72	TBD			TBD	500/460		
PowerFlow 4621[††]	RDX, 19.4	12, 60	0.83[‡‡]	0.28[‡‡]	6.49[‡‡]	5.9[‡‡]	340/240		
PowerFlow 4621	RDX, 19.4	12, 135/45	0.83[‡‡]	0.28[‡‡]	6.49[‡‡]	5.9[‡‡]	340/240		
PowerFlow 4621[§§]	RDX, 19.4	21, 120/60	0.83[‡‡]	0.28[‡‡]	11.40[‡‡]	5.9[‡‡]	340/240		
PowerFlow 4621	HMX, 19.4	12, 60	0.83[‡‡]	0.32[‡‡]	6.49[‡‡]	5.7[‡‡]	400/300		
PowerFlow 4621	HMX, 19.4	12, 135/45	0.83[‡‡]	0.32[‡‡]	6.49[‡‡]	5.7[‡‡]	400/300		
PowerFlow 4621[§§]	HMX, 19.4	21, 120/60	0.83[‡‡]	0.32[‡‡]	11.40[‡‡]	5.7[‡‡]	400/300		
PowerFlow 5008	RDX, 30.0	8, 135/45	0.98	0.11/0.13	6.03	5.8	340/240	6333	11-99

[†] 7-in., 32-lbm, L-80 casing for all other charges ‡ Temperature ratings for 1 and 100 hr [§] Estimated from 4 1/2-in. gun [††] Frac Gun [‡‡] Estimated from 4 5/8-in. guns
[§§]

Courtesy of Schlumberger

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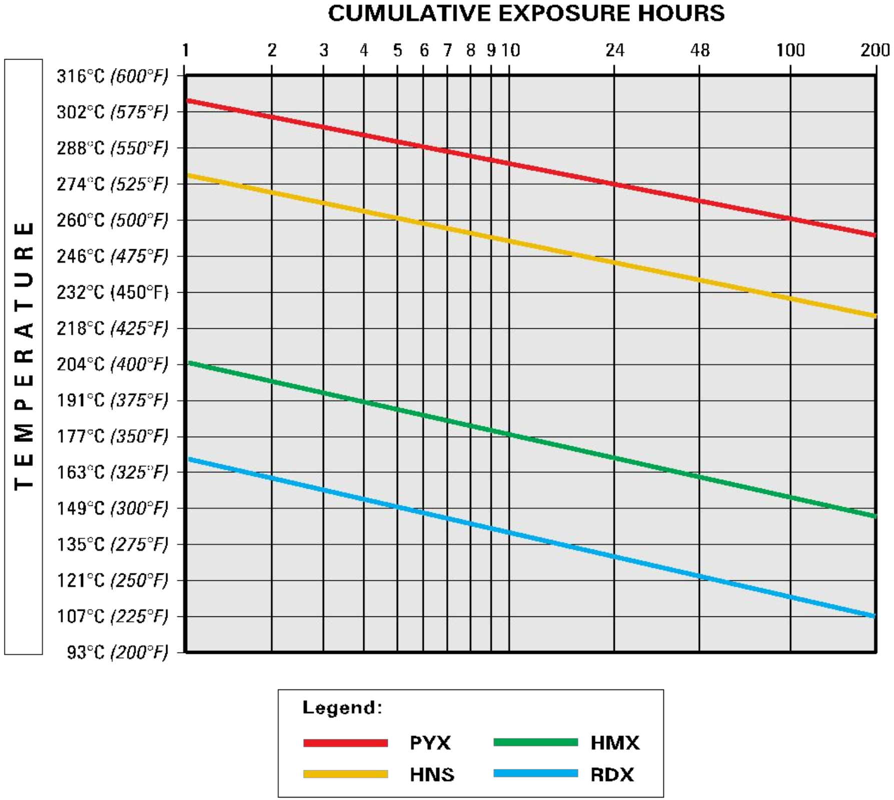
TEMPERATURE LIMITATIONS OF EXPLOSIVES

Adequate temperature rating selection is critical to the optimum performance of the charge. Factors to consider:

- Operational time (Time to deploy, RIH and activate the guns)
- Near wellbore temperature for reperforating existing wells
- Charge deterioration due to temperature will result in lower penetration



CHARGE ENTRY HOLE AND PENETRATION

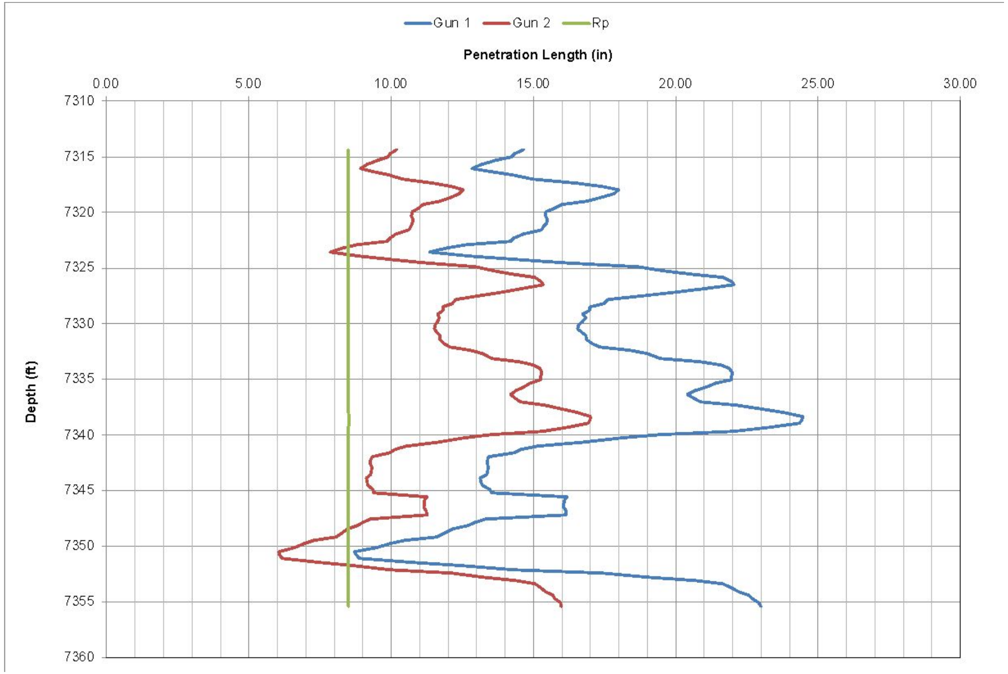
Perhaps the most controversial issue (Penetration) in gun and charge selection

- Charge penetration is not uniform
- Variations depend on rock properties and charge specifications
- Penetration should reach clean reservoir rock, it can be estimated using the Thompson correlation

$$L_p/L_{pr} = \mathrm{Exp}[0.086(c_r - c)]$$

Where

L_p Perforation length, **L_{pr}** Target penetration in reference formation
Cr Formation compressive strength, **C** compression strength of target reference fomation



MODULE 6 – SUMMARY

Optimum gun selection is a process that based on the method selected will lead to the determination of the main specifications of the gun systems, dimensions, charges and expected performance

Gun size and length depends on the well geometry, casing/tubing sizes, deviation and reservoir interval to be perforated

Selecting shot density/phasing depends of what is sought from the reservoir, large PI requires higher shot density, tunnel stability over time will require oriented perforations

Temperature has a significant effect on charge performance therefore, charges should be selected accordingly and to meet realistic operational conditions (Time)

Charge penetration will depend on rock mechanical strength, the Thompson correlation is commonly used to estimate charge's penetration

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Module 7

FACTORS AFFECTING PERFORATION PERFORMANCE

CONTENT

- *Factors affecting gun performance*
- *Perforation damage*
- *Casing/gun clearance*
- *Casing and cement properties*
- *Well fluids*

FACTORS AFFECTING GUN PERFORMANCE

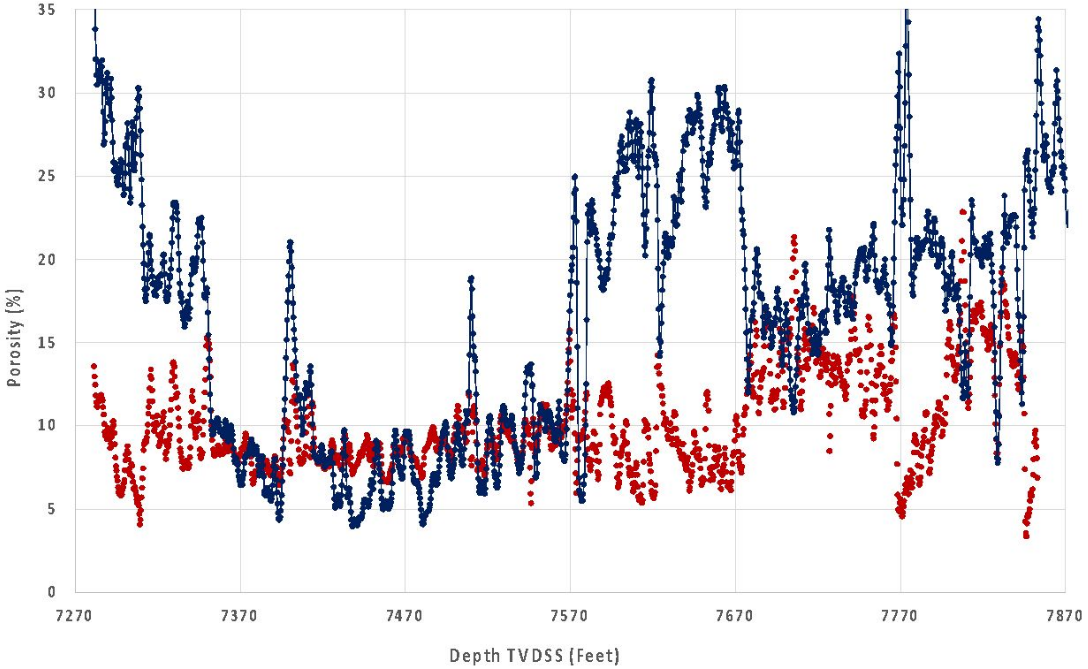
In addition to the design phase there are many operational factors affecting gun performance, these include:

- Operational time
-
- Gun and casing positioning
- Type and specifications of casing and cement
- Well fluids, type and density
- Near wellbore petrophysical properties (Porosity and permeability)

FACTORS AFFECTING GUN PERFORMANCE (Continued)

Near wellbore porosity and permeability tend to be different from those original found in the reservoir. These affect shot penetration.

- The near wellbore porosity will significantly change due to drilling and completion
- Areas of higher porosity tend to "absorb" energy from the penetrating jet limiting its reach
- Rocks of low porosity tend to allow longer charge penetration due to the lack of interaction charge-rock

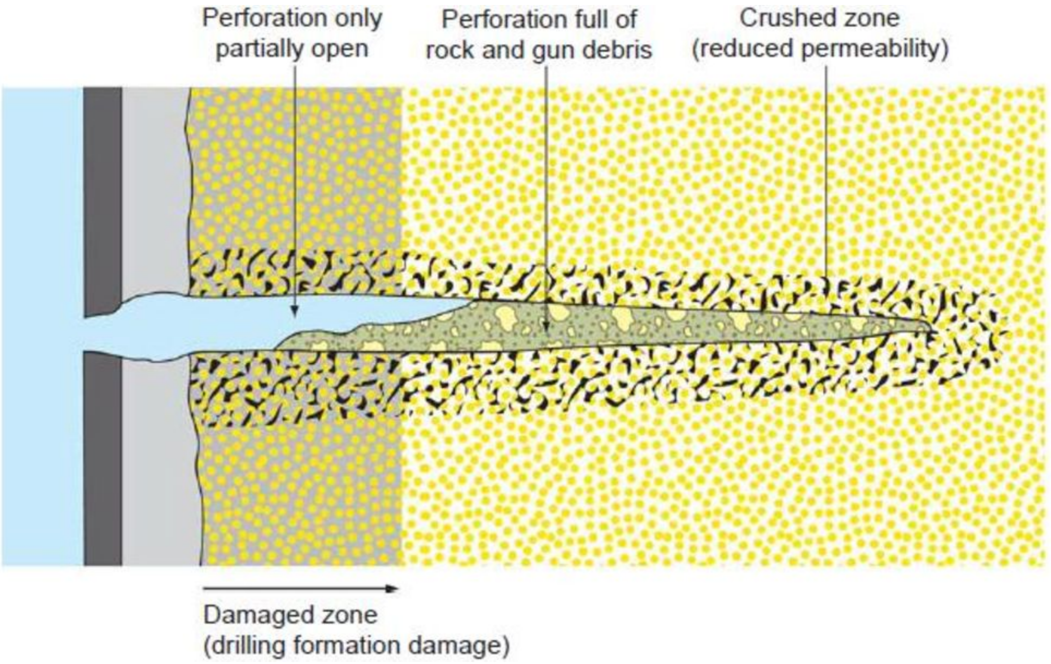


PERFORATING DAMAGE

Existing and newly created near wellbore damage will impact inflow and productivity, there over 50 types of formation damage. The ones caused by perforating include:

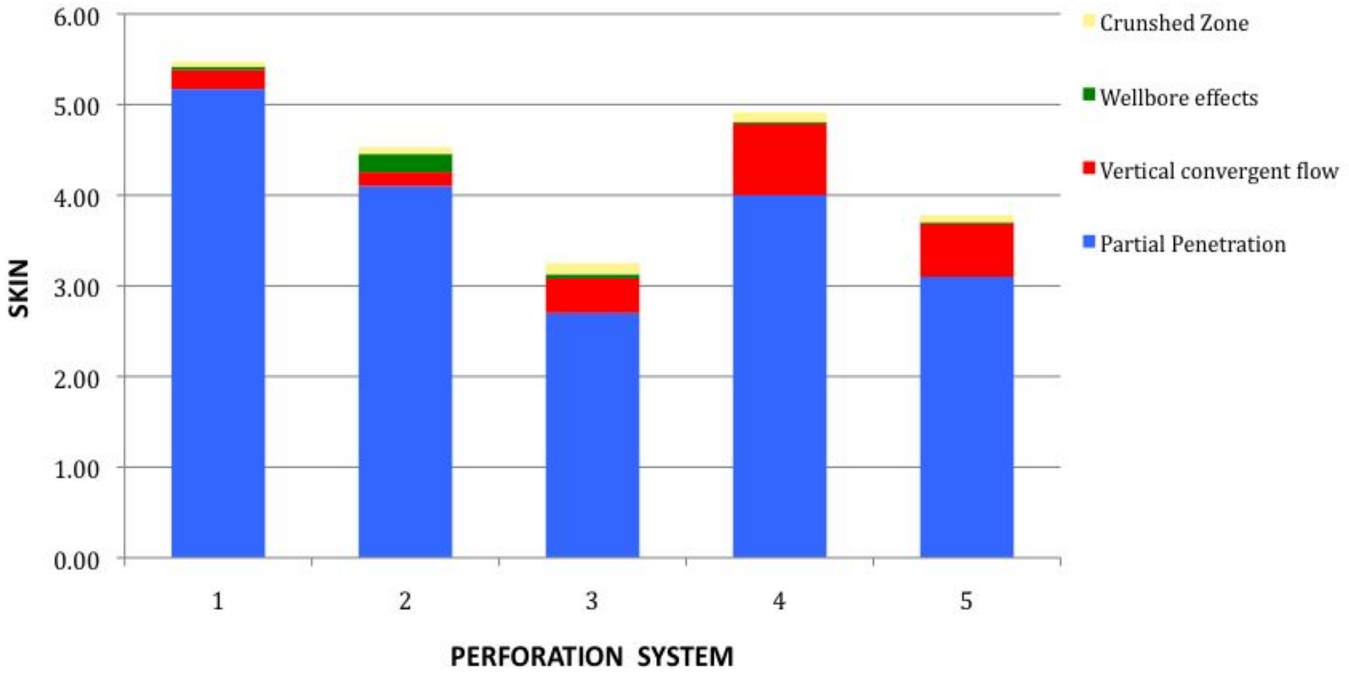
- Geometrical skin
- Partial penetration skin
- Grain crushing damage
- Flow convergence skin
- Wellbore wall effect

The most important one is the grain crushing damage as it modifies the porosity/permeability of the near wellbore



PERFORATING DAMAGE (Continued)

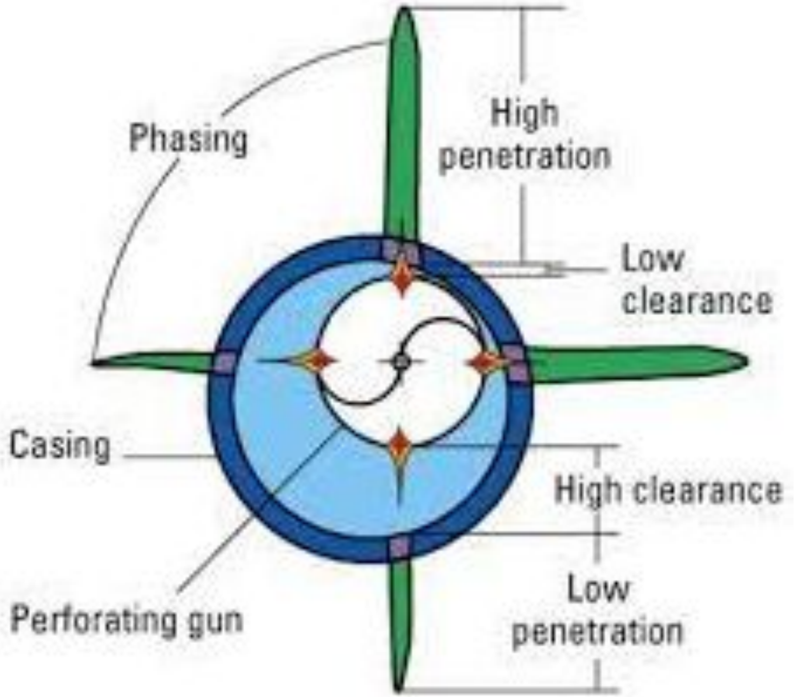
Example of perforating damage for 5 different gun specifications



CASING / GUN CLEARANCE

Position of the gun with respect to the casing is very important and can affect charge penetration.

- The closer the gun is to the casing the longer the penetration of the charge into the reservoir
- Fluid in the annular space has an cooling effect on the expelling jet



TYPE OF CASING AND CEMENT

Steel casing and cement both can affect significantly gun perforating.

- The closer the gun is to the casing the longer the penetration of the charge into the reservoir

- Casing wall thickness and grade need to be considered

- Cement sheet, thickness and compressive strength influence penetration

MODULE 7 - SUMMARY

COMPONENT	PENETRATION	DENSITY	SIZE	PHASING	DRILLING DAMAGE
Casing / Gun tolerance	∀ (red)	∀ (green)	∀ (red)	∀ (red)	∀ (green)
Gun standoff	∀ (red)	∀ (green)	∀ (red)	∀ (green)	∀ (green)
Charge performance	∀ (red)	∀ (green)	∀ (yellow)	∀ (green)	∀ (red)
Casing/Reservoir properties	∀ (red)	∀ (red)	∀ (red)	∀ (green)	∀ (red)
Completion / Gun size	∀ (red)	∀ (yellow)	∀ (red)	∀ (red)	∀ (yellow)
Deployment method	∀ (yellow)	∀ (red)	∀ (green)	∀ (red)	∀ (red)
Type of formation	∀ (green)	∀ (green)	∀ (green)	∀ (green)	∀ (red)
Well fluids	∀ (yellow)	∀ (green)	∀ (green)	∀ (green)	∀ (red)
Cleanout method	∀ (green)	∀ (green)	∀ (green)	∀ (green)	∀ (red)
Well pressure & temperature	∀ (yellow)	∀ (green)	∀ (green)	∀ (green)	∀ (green)

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Module 9
PRESSURE CONDITIONS DURING PERFORATING

CONTENT

- *Fundamentals of pressure conditions during perforating*
- *Perforating overbalance*
- *Static underbalance*
- *Principles of dynamic underbalance*
- *Extreme overbalance conditions*

FUNDAMENTALS OF PRESSURE CONDITIONS

Different well and reservoir conditions require different pressure conditions during perforating, two (2) very important issues are addressed through pressure:

1. Well control
   The need for well control is critical and is a safety priority therefore, in reservoirs that are over pressurized an strict control is required during deployment, activation and actual firing of the gun

2. Productivity impairment
   Reservoir pressures and/or firing of the gun creates pressures that push debris, fluids, solids into the tunnel causing damage.
   Additionally the creation of the tunnel generates mechanical damage that will also contribute to production impairment.

FUNDAMENTALS OF PRESSURE CONDITIONS DURING PERFORATING

Three (3) main pressure conditions are considered

1. Balance, where the wellbore pressure is equal to reservoir pressure

   $P_{res} = P_{wellbore}$

2. Overbalance, where wellbore pressure is much higher than reservoir pressure

   $P_{res} >> P_{wellbore}$

3. Underbalanced, where wellbore pressure is lower than reservoir pressure

   $P_{res} << P_{wellbore}$

Two types of underbalanced conditions are recognised: Static & Dynamic

PERFORATING OVERBALANCE

Overbalance pressure conditions are applied through the density of the perforating fluid, the magnitude of the overbalance will depend on reservoir pressure, fluid (oil/gas) and equipment pressure ratings, additionally overbalance can:

- Typical values vary between 100 psi < ΔP_{OB} < 1000 psi.
- Induce invasion of fluids and solids into the perforated tunnel and near wellbore
- Such a fluids can cause pore blocking and/or fluid-rock interaction that will result in formation damage at the near wellbore
- Might require an additional source of pressure different from fluid's density (Surface pressure)
- Fracture pressure is considered the limit of overbalance

ΔP_{OB} Level of overbalance pressure (psi)

PERFORATING UNDERBALANCE

Static underbalance

Static underbalance is based on reducing the hydrostatic pressure at reservoir level by varying the density of the perforating fluids. Downhole this can:

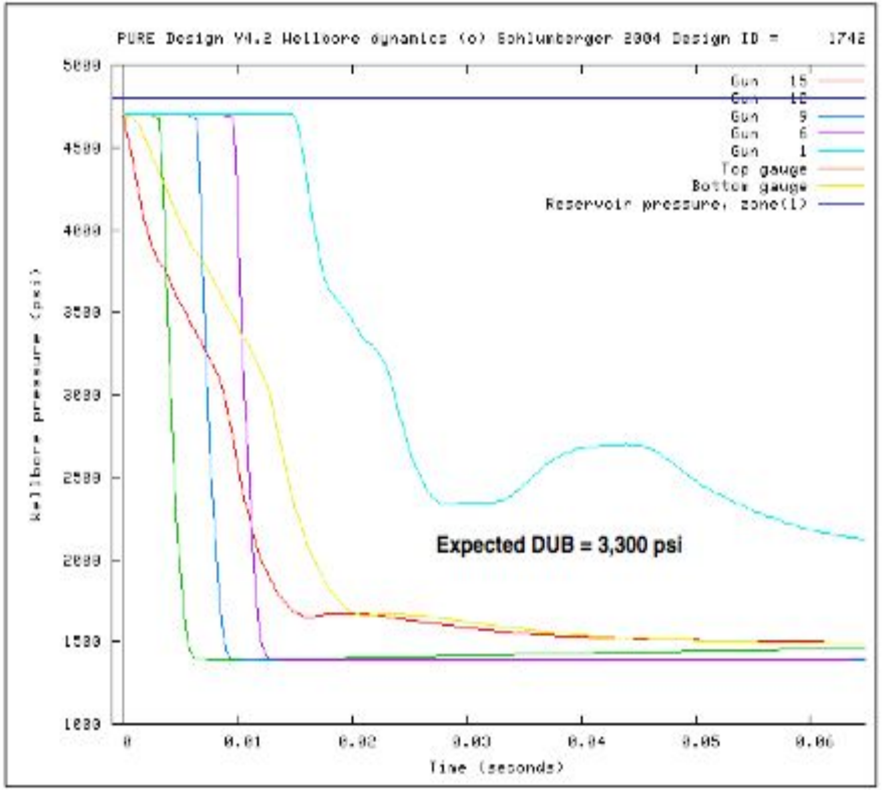
- Create a pressure lower than reservoir pressure at the interval to be perforated
- A combination of fluid/gas can be used to reduce the hydrostatic column pressure

The fact is that until the moment when the gun is activated that underbalance is present but it is overcome by the overpressure generated by the detonation of the charge

PERFORATING UNDERBALANCE (Continued)

Dynamic underbalance

- Focalized UB is generated by configuring the gun and generating negative pressures
- Technologies differ for each supplier as to the location within the gun to generated the UB pressure
- Along (SLB), in place of some charges or at the top/bottom(HES) of the gun
- Perforation’s collapse pressures can be use as a limit for the maximum level of underbalance



PERFORATING USING EXTREME OVERBALANCE

The concept is based on applying pressures that are above the formation fracture pressure to induce the initiation of a fracture as the gun is activated

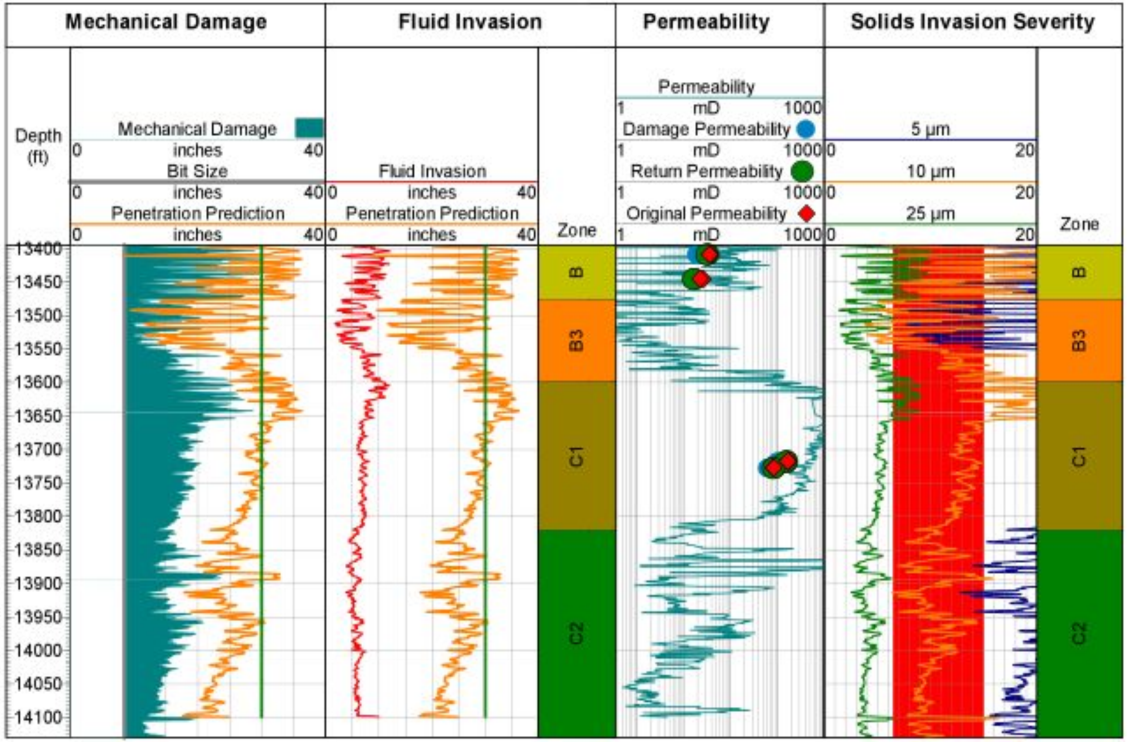
- The excessive pressures might compromise formation’s isolation and well integrity
- Pressuring the whole casing is avoided by trying to apply the overbalance only to the interval to be perforated
- The high pressure differentials induce the invasion of fluid, debris and solids into the created fracture and tunnel

PRODUCTIVITY IMPAIRMENT

Type of damage includes:

- Mechanical damage from drilling & completions
- Filtrate invasion
- Solid's invasion

Resulting in permeability impairment hence reduced inflow



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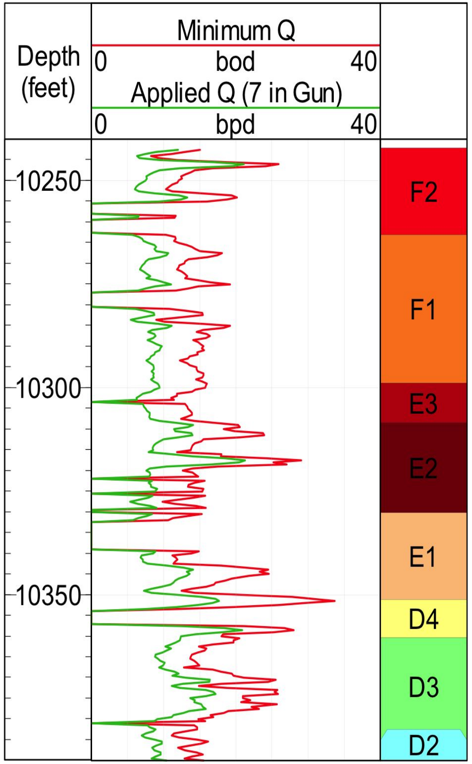
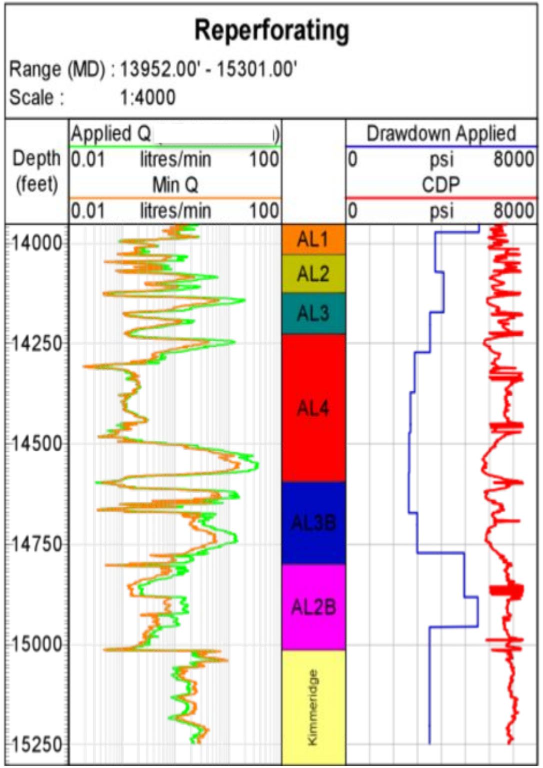
PRODUCTIVITY IMPAIRMENT (Continued)

Impaired perforation tunnels need cleaning to restore productivity. A natural way to clean the tunnels is with inflow:

- Inflow can be generated by either underbalance or drawdown
- UB will create inflow during perforating
- Drawdown will generate inflow during well start up & production
- For UB and drawdown the limit is the critical drawdown pressure
- Other methods of cleaning the tunnels include chemical treatments





SUMMARY

The selection of the pressure conditions during perforating is critical to short and long term productivity from the reservoir.

- Three (3) main scenarios exists; balance, overbalance and underbalance pressure
- Conditions such as well pressure, near wellbore impairment, equipment availability will dictate the more suitable scenario, method and guns to use
- Two (2) types of underbalance pressure conditions are available; a static and a dynamic pressure. The latter being very favourable where high formation damage is present
- The use of underbalance pressure conditions induce inflow of fluids into the wellbore enhancing the cleaning effect of the tunnels
- Well control control and productivity impairment continue to be the priority in the selection of the downhole pressure conditions

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Module 10
PERFORATING APPLICATIONS

CONTENT

- *Perforating for cement squeeze*
- *Perforating for hydraulic fracturing*
- *Perforating for sand control completions*
- *Perforating for sand management*
- *Perforating water injectors*

PERFORATING APPLICATIONS

Different well and reservoir requirements might require different perforating methods and gun design. Two(2) key issues are always critical; well productivity and safety of the operations. Other considerations include

- Gun orientation for hydraulic fracturing, frack & pack and sand management
- Perforating density for water injectors and sand control completions
- Depth control for multilayer reservoirs
- Charge penetration for competent or unconsolidated reservoir rocks

PERFORATING APPLICATIONS – CEMENT SQUEEZE

Main considerations include:

- Entry hole diameter
- Depth control
- Phasing
- Penetration

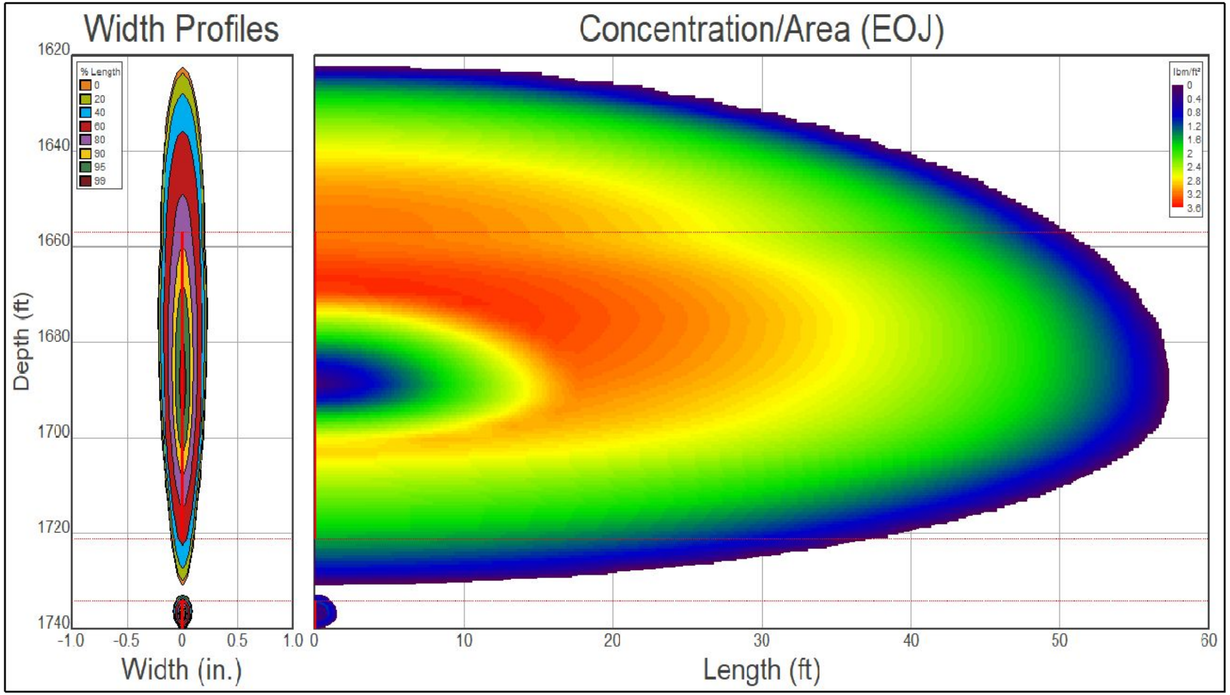
PARAMETER	IMPORTANCE	GUIDELINE
Entry hole diameter	Medium	
Length	High	For maximum flow area exposed
Density	High	4 < SPF < 8
Phasing	High	30° < phase < 120° for max. circumferential coverage
Orientation	Low	No applicable
Charges	Medium	Important to achieve good penetration
Method	High	Wireline conveyed is the preferred if possible
Fluids	High	Existing hydrocarbons or clean workover fluid
Pressure	Medium	Underbalance or near balance are preferred

PERFORATING APPLICATIONS – HYDRAULIC FRACTURING

Hydraulic fracturing is the opening of a conductive flow path in a rock with low porosity and permeability

Main considerations include

- Entry hole diameter
- Depth control
- Orientation
- Casing integrity



PERFORATING APPLICATIONS – HYDRAULIC FRACTURING (Continued)

Main considerations include

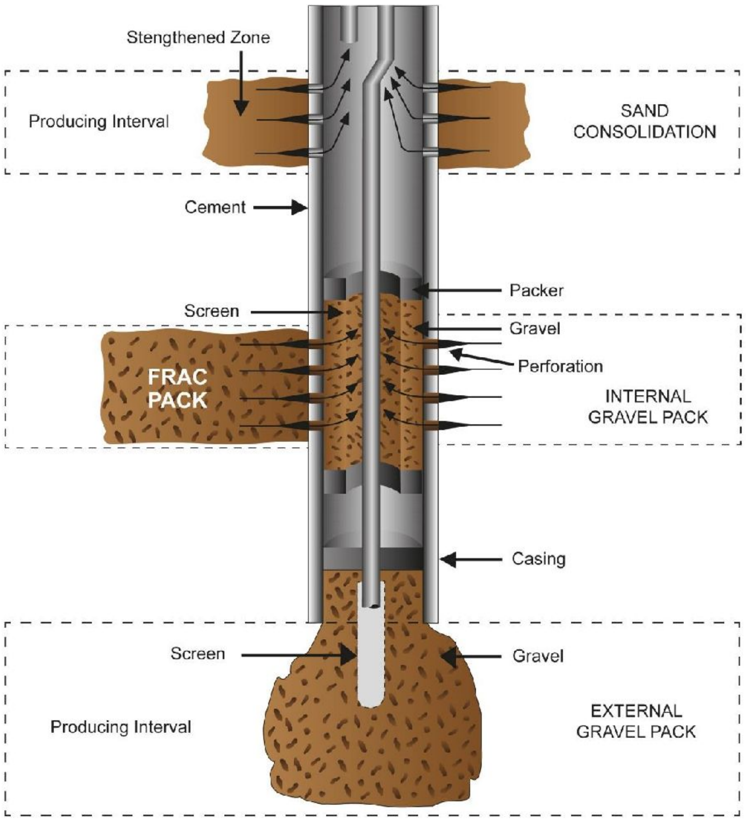
- Entry hole diameter
- Depth control
- Orientation
- Casing integrity

PARAMETER	IMPORTANCE	GUIDELINE
Entry hole diameter	High	Larger hole diameter if possible, it increases friction pressures if too small
Length	Low	Formation will be fractured so all what is needed is some penetration into the rock
Density	Medium	Depending on the flow rate, normally < 8 spf
Phasing	High	180 °, 90 °
Orientation	High	Shots in the direction of fracture propagation to avoid the tortuosity effect
Charges	Low	Sufficient to allow a short tunnel to be generated
Method	High	Wireline conveyed for satisfactory depth control
Fluids	Medium	Clean workover fluid
Pressure conditions	Low	Near balance
Main concern	Control of fracture growth, direction and orientation, casing integrity	

PERFORATING APPLICATIONS - SAND CONTROL

There are four (4) main sand control methods that require perforating, all have specific requirements

1. Internal gravel packs – Shot density and penetration
2. Frack & packs – Orientation and shot density
3. Stand-alone-screens in cased holes – Penetration and shot density
4. Sand consolidation – Shot density, entry hole diameter and fluids

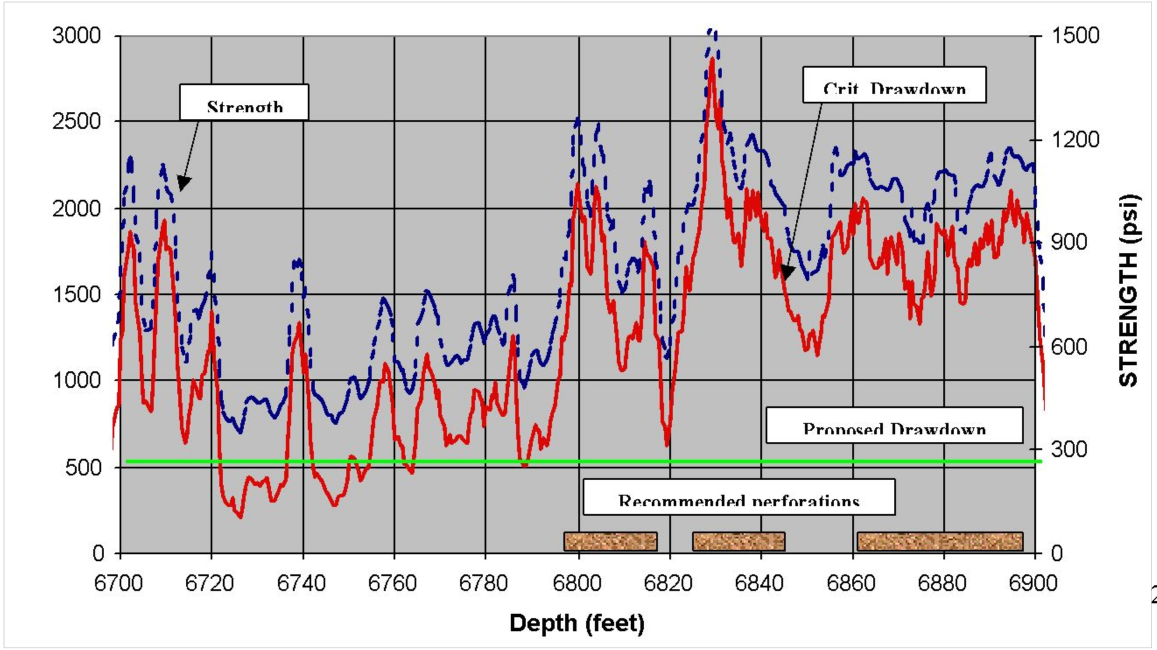


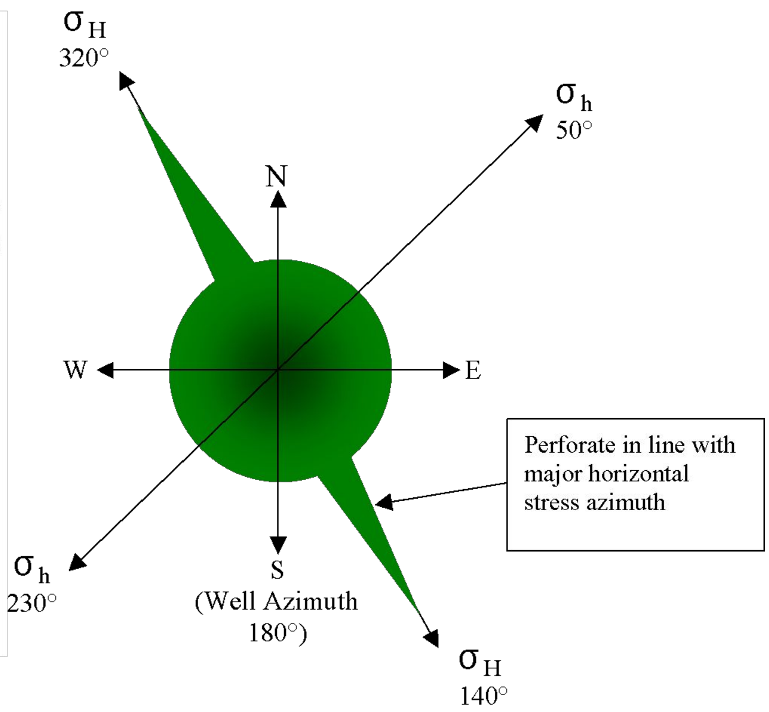
PERFORATING APPLICATIONS – SAND CONTROL (Frac & Pack)

PARAMETER	IMPORTANCE	GUIDELINE
Entry hole diameter	Medium	Sufficient to minimize friction losses
Length	Low	-
Density	Medium	4 < SPF < 6
Phasing	High	30° < phase < 120° for max. circumferential coverage
Orientation	Low	Not very important because K is high
Charges	Low	-
Method	High	Done w/TCPs for cost reasons but wireline is preferred
Fluids	Medium	Clean workover fluid
Pressure Conditions	Low	Near balance is satisfactory
Main concern	Avoid vertical fracture growth and ensure tip screen out.	

PERFORATING APPLICATIONS – SAND MANAGEMENET

Wells on sand management can be completed with selected or oriented perforations





PERFORATING APPLICATIONS – WATER INJECTORS

The main considerations in this case are

- Penetration
- Density
- Casing integrity
- Entry hole diameter

PARAMETER	IMPORTANCE	GUIDELINE
Entry hole diameter	High	Larger hole diameter to minimize pressure losses
Length	Medium	Sufficient to establish good communication with the reservoir
Density	Medium	Very dependable on K, for ↑ K there is no need to perforate high density, 4 < spf < 12
Phasing	Medium	Depend on density and well orientation, design to ensure good radial distribution of flow
Orientation	Low	Depend on well azimuth and deviation
Charges	Low	Sufficient to establish communication with reservoir
Method	Medium	Wireline conveyed for satisfactory depth control
Fluids	Medium	Existing hydrocarbons, clean workover fluid
Pressure conditions	Medium	Mainly perforated overbalance
Main concern	Casing integrity and long term performance	

SUMMARY

The selection of a perforating method and gun system is in most cases specific to the application. As a result, each application requires the ranking of the method and gun performance suitable. Among those applications we have:

- Squeeze cementing – penetration, shot density and depth control
- Hydraulic fracturing - orientation, entry hole diameter and shot density
- Water injectors – shot density, entry hole diameter and charge penetration

- There are five(5) sand control methods that require perforating; stand-alone-screens, internal gravel packs, frack and pack, sand consolidation.

Sand management requires the use of a perforating method and gun type that minimize or mitigate the stress conditions around the tunnels therefore, selective or oriented perforating are often used.

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Module 11
PERFORATING OPERATIONS

CONTENT

- *Preparing the gun system for transportation*
- *Well site preparation*
- *Depth control and gun activation*
- *Gun performance*

PREPARING THE GUN SYSTEM FOR TRANSPORTATION

The service companies store guns of different types, explosives and all the equipment required to carry out perforating operations

- Gun preliminary assembly carried out at supplier's shop. Audited by personnel from the operating company
- The audit process will assure the operators of the existence of proceses and proceedings for preparation
- Charge storage conditions and inventory is important,
- In some locations such an audit processes are also carried out by regulatory entities (Government). Military escorts are also common in some countries

WELL PREPARATION

Main considerations include:

- Equipment inventory, QA/QC prior to reach location
- Supply of services to perforating services contractor (Power, lodging…)
- Documentation of shipped equipment, certificates, inventory, permits……

Courtesy of Schlumberger

- Charge specifications and required documentation

WELL PREPARATION (Continued)

Site preparation is important in terms of facilities to be able to assemble, test, deploy, activate and retrieve the guns

Main considerations at the site include

- Electrical insolation to remove the possibility of premature firing
- Safe arming of the gun
- Day light rig operations to be planned for perforating
- Designated well area for dealing with explosives
- Build up well kill fluid volume in case of sudden/unexpected well eruption
- Check/test of all pumping equipment that might be used for well flowing, circulation or killing operations
- Clear assignment of individual responsibilities for rig personnel, service contractors and operator’s employees.

DEPTH CONTROL AND GUN ACTIVATION

Main considerations include

- Check/test of all pumping equipment that might be used for well flowing, circulation or killing operations

- Clear assignment of individual responsibilities for rig personnel, service contractors and operator's employees.

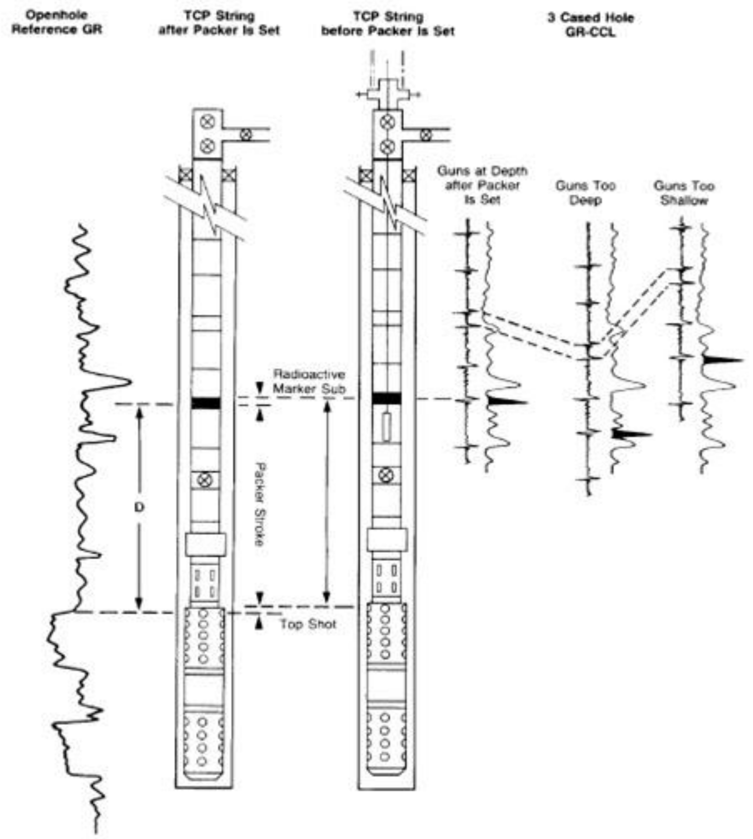
- Detailed pressure testing/recording for all surface equipment (Lubricator, BOPs)

Courtesy of SureFire Wireline LLC

DEPTH CONTROL AND GUN ACTIVATION (Continued)

Varies depending on the deployment method

1. Reference logs are existing GR, CCL
2. Wireline deployed is the most accurate method
3. Critical in multilayer reservoirs
4. Well path and need for depth accuracy will influence method selection



DEPTH CONTROL AND GUN ACTIVATION (Continued)

Documenting and reporting depth control

- Gun specifications(size, type, charges, spf, phasing)
- Rotary table depth and well information
- Reference log information such as type of log and date recorded
- Correlation log reference number, type of log and date recorded
- For GR/CCL combinations, the position of the CCL with respect to the GR is required as well as CCL firing depth

PRE & POST GUN FIRING CONSIDERATIONS

- Resolve depth discrepancies particularly where the guns are CT deployed.
- CCL should be run across(above and below) the interval to be perforated, depth recorded must be < 1.0 feet difference from the reference log.
- When perforating depth is reached, run in below the interval(3 to 4 casing collars) but without reaching HUD. Do not tag bottom(HUD), the gun might get stuck
- Confirm depth on the display(measuring device) is that of the CCL measuring point
- Pull the gun up to the CCL depth for shooting, check that casing collars are at depth
- If there are discrepancies larger than 3 feet, repeat the calculations
- Allow time for perforation debris and scale to settle before attempting to POOH

PRE & POST GUN FIRING CONSIDERATIONS (Continued)

Courtesy of Dream Stime

SUMMARY

A five (5) step process is considered for perforating jobs; equipment preparation (shop), transportation, site preparation, gun deployment and activation, post firing checks and perforation evaluation

- Because of the nature of the operations (Use of explosives) these operations are heavily regulated, monitored and evaluated
- One of the most critical steps is the deployment and activation of the gun
- A number of checks and controls are used to ensure that the gun is fired successfully at the right depth
- Logs such as GR, CCL and eventually PLTs are commonly utilised as references
- Above all the safety of the personnel and equipment is the priority at all times

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Module 12
GUN & CHARGE PERFORMANCE

CONTENT

- *Definition of performance*
- *API 19b Recommended Practice*
- *Gun performance*
- *Charge performance*

DEFINITION OF PERFORMANCE

Gun and charge performance are inherently linked even though charge performance is not necessarily a _complete_ representation of gun performance

- Operators define performance in terms of the resulting well productivity
- Service companies define performance in terms of the gun/charge functioning as being deployed, fired and retrieved safely
- Predictions of performance such as charge's penetration, EHD and inflow predictions are only estimations
- Estimations of the impact of gun performance on well productivity can be made via simulations

API 19b RECOMMENDED PRACTICE FOR EVALUATION OF WELL PERFORATOR

- 19b version issued in 2001
- Defines test conditions and specifications for the gun system and charges
- All report forms and data sheets to be filled up with the results of the test
- It also covers practices for inflow, permeability and hight temperature test conditions
- Berea sandstones and concrete targets are specified in terms of slurry formulations, curing times, target configuration and compressive strength

GUN & CHARGE PERFORMANCE

Gun performance include the correct functioning of all its components such as connectors, firing subs, ignitor, charges and safety mechanisms

Reports and studies can be use as references of gun performance along with track records of the supplier and publications

Charge performance refers to the performance of a specific type of charge as compared with the reference norm represented by the American Petroleum Institute API 19b norm

Courtesy of Schlumberger

GUN & CHARGE PERFORMANCE (Continued)

Charge performance is usually specified along with *some* performance features

- This example shows the specifications for Halliburton “MaxForce FRAC” charges
- The only performance result reported is for the entry hole diameter variation EHV (Last column)
- The data also specify the characteristics of the target but no performance

Gun Size (in.)	Charge Name	Explosive Load (g)	Explosive Type PN	Target Casing Specifications	EHD (in.)	EHV
2¾-inch 6spf 60°	150 MaxForce®-FRAC	15	RDX-102745134	4½-inch 13.5ppf P-110	0.35	2.4%
			HMX-102740045	4½-inch 13.5ppf P-110	0.35	2.4%
3⅛-inch 6spf 60°	230 MaxForce®-FRAC	23	RDX-102736069	4½-inch 13.5ppf P-110 5½-inch 23ppf P-110	0.41 0.40	2.3% 5.9%
			HMX-102732983	4½-inch 13.5ppf P-110 5½-inch 23ppf P-110	0.42 0.42	3.0% 3.8%
	210 MaxForce®-FRAC	21	RDX-102045430	4½-inch 11.7 L-80 5½-inch 23ppf P-110	0.46 0.43	4.7% 11.7%
			HMX-102127122	4½-inch 11.7 L-80 5½-inch 23ppf P-110	0.49 0.45	5.8% 13.8%
3⅜-inch 6spf 60°	230 MaxForce®-FRAC	23	RDX-102736069	5½-inch 23ppf P-110	0.40	3.5%
			HMX-102732983	5½-inch 23ppf P-110	0.40	4.3%
	210 MaxForce®-FRAC	21	RDX-102045430	5½-inch 17ppf L-80	0.43	13.1%
			HMX-102127122	5½-inch 17ppf L-80	0.45	11.7%

Courtesy of Halliburton

GUN & CHARGE PERFORMANCE (Continued)

Charge performance is usually specified along with _some_ performance features

- This example shows the specifications for Schlumberger charges
- The performance results reported are for EHD, Burr and charge penetration
- The data also specify the characteristics of the target such as strength

Charge	Explosive type, maximum weight (g)	Shots per foot, phasing (°)	Entrance hole [†] (in.)	Burr avg /max (in.)	Area open to flow (in.^{2}/ft)	Penetration [†] (in.)	Temperature [‡] (°F)	Target strength (psi)	Test date
34B HyperJet II	RDX, 21.7	12, 135/45	0.39	0.10		19.8	340/240	7020	07-95
34B HyperJet II	HMX, 21.7	12, 135/45	0.39	0.09		22.8	400/300	5816	12-92
34JL UltraJet	HMX, 22.7	12, 135/45	TBD			TBD	400/300		
34JL UltraJet	HTX, 21.0	12, 135/45	TBD			TBD	500/460		
UltraJet 5008	RDX, 25.0	8, 135/45	0.54	0.11/0.22		20.2	340/240	6629	4-00
HyperJet 4505	RDX, 38.8	5, 72	0.57[§]			37.0[§]	340/240		
UltraJet 4505	HMX, 38.8	5, 72	0.46[§]			46.8[§]	400/300		
PowerJet 4505	HMX, 38.8	5, 72	TBD			TBD	400/300		
51J UltraJet	HNS, 38.5	5, 72	TBD			TBD	500/460		
PowerFlow 4621[††]	RDX, 19.4	12, 60	0.83[‡‡]	0.28[‡‡]	6.49[‡‡]	5.9[‡‡]	340/240		
PowerFlow 4621	RDX, 19.4	12, 135/45	0.83[‡‡]	0.28[‡‡]	6.49[‡‡]	5.9[‡‡]	340/240		
PowerFlow 4621[§§]	RDX, 19.4	21, 120/60	0.83[‡‡]	0.28[‡‡]	11.40[‡‡]	5.9[‡‡]	340/240		
PowerFlow 4621	HMX, 19.4	12, 60	0.83[‡‡]	0.32[‡‡]	6.49[‡‡]	5.7[‡‡]	400/300		
PowerFlow 4621	HMX, 19.4	12, 135/45	0.83[‡‡]	0.32[‡‡]	6.49[‡‡]	5.7[‡‡]	400/300		
PowerFlow 4621[§§]	HMX, 19.4	21, 120/60	0.83[‡‡]	0.32[‡‡]	11.40[‡‡]	5.7[‡‡]	400/300		
PowerFlow 5008	RDX, 30.0	8, 135/45	0.98	0.11/0.13	6.03	5.8	340/240	6333	11-99

[†] 7-in., 32-lom, L-80 casing for all other charges [‡] Temperature ratings for 1 and 100 hr [§] Estimated from 4 1/2-in. gun [††] Frac Gun [‡‡] Estimated from 4 5/8-in. guns
[§§]

Courtesy of Schlumberger

GUN & CHARGE PERFORMANCE (Continued)

Other considerations include

- Reported charge penetration can be compared using algorithms such as the Thompson correlation. Large (>20%) over estimations are common

- Other important feature is charge debris sometimes reported by the supplier

- Manufacturing reports for the shape charges and explosives can be obtained in particular where the service contractor does not manufacture its own charges

- Physical inspection of a fired gun is a common step which confirms that all charges were fired and there was no gun/charge malfunction

GUN & CHARGE PERFORMANCE (Continued)

Courtesy of NOV

SUMMARY

Gun and charge performance relates to two distinctive sets of equipment; the actual gun and accessories and the charges placed inside the carrier

- Gun performance relates to the actual functioning of the whole system through installation, deployment, firing and retrieval

- Charge performance relates to the actual performance of the shaped charges composed of the liner and the explosives.

- Firing, penetration, entry hole diameter and overall skin generated are the major measures of performance

- API 19b is used as a reference document and serves as the bench mark for shaped charges

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