Effect of Perforation Job on Formation Damage

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ABSTRACT

The main purpose of perforating the casing or liner of a well is to form a path through which fluids will flow between reservoir and borehole. It is important that the gun properties such as shot per foot, phasing and charge type are considered in designing perforation because these factors are what determine if the operation will be successful or cause damage.

Four wells 23S, 1S, 44S, and 44T drilled in reservoir F6.00 in the Niger Delta were used as case study. Comparison was between perforations at a particular depth interval done with different gun types, and their performances in production.

The initial production in barrels and production rate of well 1S was low. The specific productivity index of 1S was 0.152bbl/day/psi/ft of perforation and was lower than all other wells. Well 44T had a specific productivity of 0.34bbl/day/psi/ft of perforation. Well 1S should have produced more than it did but did not because of the effect of formation damage.

The major effect of formation damage can be seen in the decline of productivity of the well drilled and If Perforation job is not carried out properly it could also contribute to the damage and instead of enhancing production from a reservoir it would increase the restriction to flow and thus increase the damage to formation.

In the course of this research, it has been discovered that optimized perforation design that is, the best available gun, charge, shot per foot, and phasing angle will prevent perforation increasing the damage in a formation. Perforation design should also be executed as planned and not deviated from when perforation is being carried out.

The best control technique of formation damage is prevention. Increased productivity is the most important goal in completing a well so special care must be taken to ensure that the damage is prevented from occurring.

Keywords: Formation damage, Optimized Perforation Design, Specific productivity Index, Niger Delta.

Introduction

Oil and gas wells may have permeability reduction around the wellbore due to drilling mud, cement solids and filtrate invasion into the formation. This is generally referred to as formation damage or drilling damage. Formation damage may be defined as a reduction in the original value of either the absolute permeability of the rock or the effective permeability to the formation fluid in the vicinity of the wellbore. The zone of reduced permeability is called the skin, and the resulting effect is called the skin effect.

In the majority of completions, once the reservoir has been drilled, production casing or a liner is run into the well and cemented in place. To provide the communication between the reservoir and the wellbore, it will be necessary to produce holes through the walls of the casing, the cement sheath and penetrate into the formation. This is accomplished by a technique called perforation but the disadvantage is that perforating can lead to "skin damage", where debris from the perforations can hinder productivity of the well.

Formation damage caused by perforating is one of the highest risks in well completions. Common types of damage that can occur inside the perforation tunnel are fractured and compacted zones, perforation gun debris, and broken formation blockages. Reducing or eliminating initial perforation damage results in a more productive well over its lifetime.

Ineffective perforation can adversely affect the completion of fracture stimulated wells in several ways. If the interval is to be tested prior to fracturing, a clean connection to the formation is required to facilitate meaningful data acquisition. Excessive damage caused by perforation can mask true formation potential and lead to incorrect diagnosis and decision making. Inadequate perforations can result in significant fracture tortuosity, increasing formation breakdown pressure – occasionally beyond the capacity of surface equipment or design rating of the well. Traditional methods for achieving clean perforations

depend on creating a pressure gradient between the formation and wellbore to induce flow and remove debris from the perforation tunnels - this can be difficult to accomplish, especially in low-pressure reservoirs.

Cleaning up after any well operation is critical. During perforation, a high-energy jet from an explosive shaped charge shoots through the casing and cement, and pierces the formation, creating a conductive path deep into the reservoir rock. Immediately after gun detonation, fluid from the borehole fills the perforation tunnel. This initial contact between the wellbore fluid and formation may cause an additional reduction in permeability and a decrease in perforation efficiency. This is particularly true in overbalanced perforating, a condition in which the wellbore hydrostatic pressure is greater than formation

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pressure. Thus in order to maximize hydrocarbon recovery perforation must be properly oriented, debris from the perforation tunnels must be effectively removed(debris includes not only loose material in the perforation tunnel, but more importantly, crushed sand grains that line the tunnel and constitute what is known as perforation damage) and formation damage must be minimized during the process.

RESEARCH APPROACH

The aims and objectives of this project will be achieved by making analytic comparison between perforation results from different wells in the same reservoir at a particular interval. The primary cause of wellbore damage and reduced production in any perforated completion is the invasion of pulverized rock formation grains that create a restrictive "low-permeability crushed zone. The damage caused by perforation can lead to a decline in the production of hydrocarbons from the reservoir. In order to maximize productivity the problems associated with perforation as well as the formation damage caused by it ought to be taken into consideration in the designing of perforation operations.

Statement of Theory and Definitions

Numerous investigators have studied the effects of perforation job. Perforating is a vital part of well completion operations thus if it is incorrectly carried out, the productivity of the well will appear to be low, which may result in individual productive zones or even an entire field being mistakenly condemned and possibly abandoned.

A number of types of completion techniques have been developed, and the method selected for a given application depends on the characteristics and location of the formation.

PERFORATION TECHNIQUES

There are two main categories of perforators-wireline conveyed and tubing conveyed

Wireline Conveyed

Wireline perforating guns are run into the well on electric cable detonated by passing a current down the cable (See Fig 1). These guns are largely constrained by two factors

- The diameter must be less than the casing inside diameter. This allows a large diameter gun to be used and hence a large charge
- The length of gun is defined by either the weight which can safely be suspended by the wireline or by the length of lubricator into which the guage will be retrieved after perforating in underbalanced conditions.

Wireline conveyor perforators could be further sub-divided into three classes, depending on the type of charge carrier used:

(1) Retrievable tubular steel carrier guns

A retrievable steel carrier gun consists of a cylindrical steel carrier which houses the shaped charges mounted opposite indentations in the cylinder walls. The steel carrier is retrieved from the well after perforating. This type of perforator leaves no gun debris and (because most of the explosive energy not used in producing the jet is absorbed by the gun carrier) does not cause casing damage.

(2) Expendable or non-retrievable guns

The expendable and semi expendable guns are run through tubing after the well has been completed. The pressure in the wellbore can then be reduced below reservoir pressure so that there is an inflow immediately after perforating. This sudden inflow helps to "clean" the perforations. The expendable type of perforator disintegrates entirely when fired. The major disadvantage of the expendable perforator is the large amount of debris left in the hole.

(3) Semi-expendable guns

The semi-expendable jet perforator has a straight or twisted steel bar with holes or twin wire strips shaped to support the perforating charges. This type of perforator leaves less debris in the wellbore than the completely expendable type and, for a given gun "outside diameter" (O.D.), can carry a larger charge than is housed in a steel carrier tube. Like the fully expendable perforator, it can cause casing damage. The explosive is sometimes cased in a glass or ceramic housing (rather than metal) since this breaks up into minute particles on firing, thus reducing the gross volume of gun debris.

Tubing Conveyed perforating guns

Tubing conveyed perforating, or TCP, involves the assembly of a perforating gun on the end of the drill pipe string, production tubing or coiled tubing and its lowering and positioning in the wellbore prior to detonation. After detonation the gun can either be pulled from the well or detached to drop into the wellbore sump below the perforation (Fig 2). TCP is advantageous because of the guns ability to use high shot densities and to create large entrance hole sizes. This allows higher flow rates to be realized without formation breakdown. It also allows for creating perforations simultaneously, which benefits well clean up and productivity.

PRINCIPLES OF SHAPED CHARGES

The main explosive is contained within a charge container which will be shattered during the explosion. A metal case assists in containing and directing the force of the explosion to a certain target area. To concentrate the impact of the explosive force on the target the charge case is normally designed with a conical liner. When the explosive is detonated, the symmetry of the charge causes the metal liner to collapse along its axis into a narrow, focused jet of fast moving metal particles. When the charge is positioned perpendicular to the wellbore casing, the jet penetrates the casing, and the surrounding cement sheath and formation rock. This is a displacement mechanism where the steel, cement and rock are pushed aside by the jet, a process that continues until the speed of the jet falls below some critical velocity and cannot penetrate further. The jet leaving the charge has a velocity of the order of 20,000ft/sec and has an impact pressure on the casing of 5 x 10 psi. Under such high impact pressures, the casing material that it contacts becomes plastic and moves away from the impact of the jet. The penetration is due solely to the extremely high impact force exerted on the target by the jet.

The factors influencing Charge Performance are

- Penetration length
- Perforation diameter
- Perforation hole volume
- Burr height on the inside of the casing around the perforation entrance hole

All perforation flow patterns are utilized. 90 phasing which provides the best radial depletion can be very effective when conducted with high shot densities. However, the selection of phasing will depend not only on shot densities but gun size, gun clearance, formation isotropy or anisotropy with respect to permeability.

The pressure differential between a well bore and the reservoir prior to perforation can be described as underbalanced, balanced or over-balanced. A desirable underbalance condition exists when hydrostatic pressure inside the well casing is less than pressure in the formation.

Under-Balanced Perforation

Under-balance perforating is the most common optimization technique, whereby the hydrostatic pressure in the wellbore is reduced prior to perforating to create a pressure difference between the formation and wellbore. As the tunnel is created, this pressure difference induces flow from the formation towards the wellbore. Given sufficient pressure difference and formation permeability, enough flow velocity can be generated to destabilize the crushed zone and convey the plugging material into the wellbore. Some, or all, of the compacted fill may also be removed from the tunnel tip (Devadass, 2007).

Under-balanced perforation improves flow channels by effectively removing the crushed zone through an instantaneous surge of fluids from the reservoir into the wellbore when the jet penetrates the rock.

Over-balanced Perforation

In over-balanced perforation the hydrostatic pressure in the wellbore is higher than the formation pressure. Perforation shock waves and high impact pressure shatter rock grains that break down inter-granular mineral cementation and de-bond clay particles (Fig 6). This creates a low permeability zone in the formation around perforation tunnels to reduce flow potential.

BALANCED PERFORATION

In this type of perforation the hydrostatic pressure is maintained at a pressure close to the formation pressure.

PERFORATION DAMAGE

Van Everdingen and Hurst are the originators of skin effect concept in BHP build-up curve. Their findings are based on sound mathematical deductions and reservoir engineering concept. Other authors (Harris, 1966; Nisle, 1958 and James, 1969) also have given the idea that partial perforation of a well gives rise to restriction to flow.

Total skin can be represented as the sum of skin due to formation damage by mud/cement, skin due to partial penetration, skin due to perforation, and skin due to non-darcy flow.

Perforations disturb the fluid flow and generate additional flow convergence in the near-wellbore region. The fluid flow towards the perforation tunnels is 3 dimensional. Compared to an ideal open hole, an ideal perforated well may experience additional pressure gain or loss. If the well is densely perforated with clean deep penetrating perforation tunnels, then the total communication surface area between the perforated well and the formation may be greater than that between a vertical open hole and the formation. In such a case, the perforated well may require a lesser drop, and perforating could actually improve the well productivity. On the other hand, if the well is sparsely equipped with short perforations, then perforating causes additional pressure drop in the near-wellbore region, and reduces the well productivity (Yildiz, 2006).

The ultimate test of perforation effectiveness has usually been the well productivity. As a result, much attention has been devoted to the laboratory test of perforating equipment and perforations so generated as a means of predicting and improving the well performance.

IDENTIFICATION OF PERFORATION DAMAGE

Perforation damage is often suspected when the well is producing below expected productivity index. Some tests are carried out to identify damage

- Resistivity Logs: The degree and depth of filtrate invasion during drilling can be estimated from deep, medium and shallow resistivity devices (e.g Laterolog)
- Production History review: The production performance of a well change with time and analysis of historical capacity plots for any well can be quite useful for detection of possible formation damage.
- Pressure transient well test analysis: pressure transient well test analysis is perhaps the most effective field technique for detection of formation damage. Buildup and drawdown tests can be used to establish the existence of formation damage. The skin due to mechanical factors can be computed.

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• Damaged downhole equipments: the presence of damaged subsurface equipments as a result of gun blast debris is a sign of formation damage.

EFFECTS OF PERFORATION DAMAGE

As effective as perforation process is in creating a hole or tunnel, it alters the rock formation around the ¹/₄ to ¹/₂ inch diameter tunnel, which is created. This altered, compacted or crushed zone is believed to be responsible for permeability of the zone being significantly less than virgin formation by as much as 80%. Also if proper cleanup of debris is not carried out it could lead to further impairment of fluid flow.

In some cases metal pieces from perforation blast might not be removed and thus hinder completion. They would have to be removed before production can commence. In some cases it could lead to damage of subsurface equipments.

The major effect of perforation damage is seen in the production. Flow efficiency is affected by such conditions as the number of perforations actually open to flow, degree of damage around the perforations, formation physical properties, in-situ stress conditions influencing the perforator penetration, and extent of formation crushing around the perforation. This complex interaction of perforating geometry, formation characteristics, and perforating environment precludes traditional, global solutions to design or analyze perforated completions in order to achieve optimum productivity results (Agiba and El-Assal, 2003).



Figure 1: Factors affecting perforation efficiency and productivity

PERFORATION EFFICIENCY

The main aim of perforation is to enhance production. The factors which have been highlighted as contributing to perforation efficiency are

- Formation properties: The penetration of a perforation is influenced by the compressive strength of the formation. For jet perforators, penetration depth decreases as the compressive strength of the formation increases.
- Clearance: Clearance, which is the minimum distance along the jet axis between the gun body or charge case and the target surface influences both hole size and depth of penetration. Depending on charge and gun design, a jet gun usually achieves its maximum penetration and hole size at a clearance of zero to 0.5 inch (1.2 cm).
- Phasing: The choice of phasing angle to use affects the perforation results (see Fig 8) In some cases it helps to reduce sand failures in soft formation (George, 2009)
- Perforation Plugging: Perforations tend to be filled with crushed formation rock, mud solids and charge debris when perforating in mud. These plugs are not readily removed by back flowing, especially if the formation around the perforation has been compacted. The pressure difference between formation and wellbore necessary to initiate flow varies from one plugged perforation to another, consequently when a few perforations requiring a low pressure differential have been opened up, the flow through them makes it difficult to create the greater drawdown needed to open up more perforations.
- Clean-Up of Perforation: Perforations should be cleaned immediately after shooting; once cleaned, they should be subjected to injection only with clean fluids. Flowing the well, Under balance perforating (or "perforating under drawdown"), Backsurging, Perforating washing, Acid treatment are ways of cleaning perforation.
- Perforating Density: The optimum perforation density depends on the formation permeability and the length of the perforated interval. In all oil or gas wells, the number of perforations must be sufficient to give the required flow with reasonable drawdown.
- Temperature and pressure: In deep -well perforating, perforator temperature and pressure ratings are important in optimising perforator performance. Bottom hole pressure may impose limitations on some exposed charge guns but is rarely a problem where steel carrier type guns are to be used.
- Gun penetration depth and type: gun penetration depth from API-RP 43 (Section II) data can be used to estimate the gun penetration depth into the actual formation rock provided the compressive strength of the formation rock is know. To maximize productivity, perforations must penetrate substantially beyond the zone of drilling damage, and they must be of the highest possible quality (Klotz, Krueger, and Pye, 1974). The API-

RP 43 Test is based on a compressive strength ranging from 41.34MN/sq.m to 55.12MN/sq.m (week, 1974). The productivity method of evaluating gun perforating has also been devised to measure the effectiveness of perforating under stimulated well conditions. Extensive testing of jet perforators has indicated that the fluid in the well and the direction of pressure differential between the formation and the well bore while perforating (Overbalanced and underbalanced), as well as the design of the charge and gun, may significantly affect the productivity of perforated completions (Allen and Worzel, 1956).

• Charge type: The charge type used could be either be a deep penetrating (deep penetrating, but smaller entrance hole at casing wall) or big hole (bigger hole but much lower penetration in the rock). A big hole and a deep penetrating charge produced with the same 34 grams of powder resulted in the BH charge making a 1" diameter entrance hole 8.8" long, while the DP charge produced a 0.55" hole diameter and 17.3" of penetration (King, 2009).

CASE STUDY

The case study used was gotten from Niger Delta Basin in Nigeria. F6.00 is a sandstone reservoir which was split into different blocks as a result of faults that have developed. The reservoir properties in each block are similar therefore all perforations were done under similar reservoir conditions. The sonic log reading for the reservoir is 85sec/ft which shows that the sandstone is well consolidated. As a result there was no need for sand control.

Four wells drilled in different blocks with perforation jobs carried out are considered. These wells are well 23S, 1S, 44S, and 42T. The perforation was carried at about the same level and as such perforation details (results) would not be impacted by depth differences (same reservoir). The four wells considered are untreated i.e. there was no need for sand control e.tc. This is because at the reservoir depth the sant is considered to be consolidated. Information such as the perforation details, penetration, and gun type were gotten from the field's well book.

PERFORATION DETAILS

WELL 23S

DATE: October 1993 GUN TYPE: Schlumberger TCP, RDX charges, Big Hole. PENETRATION: 6'' COMPLETION DETAILS: 4 ¹/₂'' size gun 12 SPF, 10ft of perforation, 135/45° phasing DEPTH: 11058ft

WELL 1S

DATE: June 1995 GUN TYPE: Dp, Tcp PENETRATION: 52" COMPLETION DETAILS: 4 5/8" size gun 12SPF, 10ft of perforation DEPTH: 10782ft

WELL 44S

DATE: December 1996 GUN TYPE: Schlumberger gun TCP, high shot density gun, deep penetrating, RDX charges, 45° phasing angle GUN PENETRATION: 17.9" COMPLETION DETAILS:

• 4 ¹/₂" size gun 12SPF, 4ft of perforation

• 4 ¹/₂" size gun at 6ft of perforation

DEPTH: 10782 and 10786

WELL 42T

DATE: November 2004 GUN TYPE: Baker atlas deep penetrating gun PENETRATION: 19.2" COMPLETION DETAILS: 2" size gun 6SPF, 20ft of perforation, 60° phasing DEPTH: 10782

CUMULATIVE PRODUCTION FROM EACH WELL

The cumulative oil production from the different wells is shown below in table 1.

	Table.1:	Cumulative	production
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WELL NAME	CUMULATIVE
	PRODUCTION (bbl)
238	220,000
1S	400,000
44S	90,000
44T	3,000,000

PRODUCTION IN BARRELS AFTER FOUR YEARS

Below is a table showing the production from each well for a period of four years.

TIME (YEARS)	238	15	44S	42T
1	115,000	70,000	52,000	750,000
2	65,000	95,000	38,000	730,000
3	39,000	115,000	-	270,000
4	1,000	120,000	-	500,000
5	-	-	-	250,000

PRODUCTION RATES FOR EACH WELL PER DAY

The table below shows a comparison of the production rates in bbl/day for each well.

TIME (YEARS)	238	18	44S	42T
1	315	192	142	2055
2	178	260	104	2000
3	107	315	-	740
4	3	329	-	1370
5	-	-	-	685



Figure 2: Production rates with respect to time.

SPECIFIC PRODUCTIVITY INDEX FOR PERFORATED INTERVALS

A comparison of productivity indices of different wells in the same reservoir indicates some of the wells might have experienced unusual difficulties or damage during completion. Productivity indices may vary from well to well because of the variation in thickness of the reservoir. It is therefore important to normalize the indices by dividing each by the thickness of the perforation. The specific productivity index for each well is calculated using the formula below

$$J_s = \frac{J}{h} = \frac{flowrate}{h(p_e - p_w)}$$
 bbl/day/psi/feet

Where J is the specific productivity index in bbl/day/psi/feet

h is the perforation thickness feet $(P_t - P_w)$ is the drawdown in psi Flowrate in bbl/day/psi

The takeoff flow rate will be used to calculate the specific productivity index of the perforated interval because it shows the initial performance of the perforation and is best used for judging the perforation efficiency.

From well completion data the drawdown for the wells is 250psi.

DISCUSSION

The perforation data from each well shows the effect of using different perforating guns on the same kind of formation. The cumulative oil production data from each well shows more cumulative production from the well 42T. Well 1S was perforated with a deep penetrating charge for an interval of 10ft. The gun type used has a standard penetration of 52" and a gun size 4 5/8". This type of gun is expected to penetrate deep into the formation beyond any wellbore damage in the formation.

Well 23S was completed with a 4 $\frac{1}{2}$ " gun size for an interval of 10ft. A big hole charge was used to perforate and the perforation gun has a standard penetration of 6". The penetration is low because big hole charges have lower penetration than deep penetrating but the hole size is big.

Well 44S was completed with a 4 $\frac{1}{2}$ " size gun and 10ft of perforation. High shot density gun with deep penetrating charges was used for perforation. The gun used has a standard perforation penetration of 17.9".

Well 42T was perforated with a deep penetration gun and 6 shots per foot. The gun type used has a standard penetration of 19.2". Perforation interval is the largest with 20ft of perforation. In a formation with good permeability the increase in perforation interval enhances production.

Table 4: Calculations for specific productivity index

WELL NAME	TAKEO FF RATE (bopd)	PERFORATI ON THICKNESS (ft)	PRODUCTIVI TY INDEX (bbl/day/psi)	SPECIFIC P.I (bbl/day/ps i/ft)
23S	480	10	480/250	1.92/10
			=1.92	=0.192
1S	380	10	380/250	1.52/10
			=1.52	=0.152
44S	680	10	680/250	2.6/10
			=2.6	=0.26
42T	1700	20	1700/250	6.8/20
			=6.8	=0.34

ANALYSIS

The hole created in the internal surface of the casing or liner by the perforating charge or bullet should be clean, free from burrs and round to create an efficient flow path between the reservoir and wellbore. Depending on gun size and standoff, the entrance hole is typically between 3/8" and 1/2" in diameter. The perforation charge design generally is optimized to provide maximum penetration while achieving a medium-size entrance hole.

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Well 1S is a clear case of reduced perforation efficiency as such increased mechanical skin when compared to the other wells. The data collected from F6.00 shows poor perforation efficiency of well 1S. The following can be deduced from the specific productivity index, production, and rates with respect to time.

- The specific productivity index shows the perforation performance. When there is damage to the formation effects are clearly seen from the takeoff rates. From table 4, 1S shows the lowest value of specific productivity index (0.152). The low value of productivity index indicates an increase in skin or damage in comparison with the other wells.
- From table 2 the production from well 1S was initially low (70,000 bbl). The rates then began rising gradually to 95,000bbl in the second year of production and 115,000bbl the following year. A reduction in damage will increase the production from the well.
- From table 4 the takeoff flow rate for 1S was the lowest indicating a lower performance in comparison with the other wells and more restriction to flow. The production rate of 1S for the first year was much lower than the second year. It is seen more clearly in figure 1 which shows the production rates with respect to time.
- Well 1S was shot with a gun having a standard penetration of 52 inches (API test on concrete). The perforation system stability depends on penetration depth. It decreases as penetration depth increases. The perforation penetration of 1S is high and could also be unstable thus contributing to impairment of flow.
- Well 23S and 44S have similar perforation specifications. The difference in the specific productivity index for the perforated interval is as a result of the big hole charge used for well 23S which cannot penetrate deep into the formation. Big hole charges have lower penetration than deep penetration.

It is important that the gun properties such as shot per foot, phasing and charge type are considered in designing perforation. Intact rocks between perforations stabilize the rock and prevent massive sand production. Fewer perforations, well distributed radially around the wellbore, have a better chance of attracting sufficient inflow to effectively clean up the tunnel. If cleanup is not achieved the debris will not be removed and cause impairment to flow. By shooting with low shot density gun and higher phase angle it is possible to avoid overlapping the shock damaged zones of individual perforations.

The major effect of the damage in well 1S is seen in the productivity of the well. The specific productivity index of the well was low and this affected the productivity. Production would have been better if the damage was reduced.

CONCLUSION

From the analysis on the wells drilled in F6.00 the major effect of damage can be seen in the reduced production from the well 1S. 1S shows lower specific productivity index because of the increase in damage. When the formation is damaged the flow is restricted and this leads to reduced productivity.

It was also observed that presence of cuttings and debris from Perforation job also contributed significantly to the damage and instead of enhancing production from the reservoir it increased the restriction to flow and thus increased the damage to formation.

It is highly recommended that optimized perforation design that is, the best available gun, charge, shot per foot, and phasing angle is used in order to prevent perforation increasing the damage in a formation.

Perforation design should also be executed as planned and not deviated from when perforation is being carried out.

REFERENCES

[1] Allen, T. O. and Worzel, H. C., 1956 "Productivity Method of Evaluating Gun Perforating", Spring Meeting of the Southwestern District, Fort Worth, Texas. March. [2] Bell, M.R.G., Hardesty, J.T., Clark, N.G., 2009 "Reactive Perforating: Conventional and Unconventional Applications, Learnings and Opportunities", paper SPE 122174, SPE European Formation Damage Conference, Scheveningen, The Netherlands, 27-29 May. [3]Bell, W., Brieger, E. and Harrigan, J., 1971 "Laboratory Flow Characteristics of Gun Perforations", paper SPE 3444, presented at the, 46th SPE Annual Fall Meeting, New Orleans, 3 -6 October. [4] Bell, W. T., Sukup, R. A. and Tariq, S. M., 1995, Perforating, SPE Monograph,. [5] Economides, Michael J.Hill, A. Daniel.and Economides, Christine E. 1994. Petroleum Production Systems, first edition. Upper Saddle River, New Jersey:Prentice Hall. [6]Handren, P.J., T.B. Jupp, and J.M. Dees, Oryx Energy Co., 1993 "Overbalance Perforating and Stimulation Method for Wells", paper SPE 26515, presented at the 68th Annual Technical Conference and Exhibition of the Society of Petroleum Engineers, Houston, Texas, 3-6 October. [7] Melvin Devadas 2007 "Increasing oil well Productivity by maximizing under balance during perforation" 3M oil and gas publication.

[8] T. O. Allen, H. C. Worzel 1956 "Productivity Method of Evaluating Gun Perforating." Drilling and Production Practice, American Petroleum Institute.