

COMPARISON BETWEEN PERFORATING SYSTEM AND STUDY OF PERFORATING EFFICIENCY

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Synopsis

The major objective of perforating is to provide an effective flow communication between wellbore and formation, and achieve adequate well productivity. Perforating techniques and equipment that are used play an important role in determining the production that results.

This paper describes the various perforating system used in the oil industry, with the guns and techniques that are commonly used, applications and limitations of each. Studies also include factors that affect the well productivity as well as other parameters that influence the decision making in choosing the right perforator/gun under existing conditions. Actual data from a local oil field are used as a case study and the performance of different shaped charge are simulated using the Schlumberger SPAN OIL software. The results agree with the previous findings, guns having high shot density, deepest penetration, best phase angle under reverse-pressure condition give the best productivity.

Introduction

The productivity of a perforated completion has been studied by various investigators in the past. The first studies were done using electrolytic analog model. Later, M.H. Harris¹ used the finite-difference technique to obtain productivity data from an idealized perforation system having wedge-shaped perforation. K.C. Hong² used a similar model to extend results to cases involving a *damaged zone* around the wellbore with 90, 120 and 180 phasing. All these early studies assumed flow through clean, undamaged perforation. W.T. Bell³ et al using a finite difference technique and experimental data concluded that perforating produces a damaged zone surrounding the perforation in which the permeability is reduced to 10-20% of the virgin formation.

J.A. Krueger Klotz⁴ et al were the first to apply the finite element method to evaluate the productivity of perforation with a compacted zone. S. Locke⁵ applied finite element method using 3-D model and proposed a new method for predicting the theoretical productivity ratio using nomograph by considering the *crused zone* and *damaged zone* effect. S.M. Tariq⁶ et al using the finite element analysis to evaluate the steady-state flow near wellbore region in the presence of anisotropy, shale laminations and natural fractures.

Perforating System

Essentially there are two main perforating system used in oil industry:

- a) Conventional wireline perforating system
- b) Tubing conveyed perforating system

Conventional wireline perforating system as implied, is a method of perforating the well casing with perforating guns suspended from surface using wireline equipment. Whereas tubing conveyed perforating (TCP) system consists of a casing perforating gun run into the well on the bottom of a string of production tubing or drillpipe.

Both system are grouped for their own application and limitation in certain conditions. The perforating equipment and techniques used also differ from each other.

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i) Positive-pressure or overbalanced perforating

The positive-pressure perforating is a technique of perforating with well pressure greater than formation pressure as shown in fig. 1(a).

Large diameter casing guns together with gamma-ray or neutron tool and collar locator are run through as to depth using cable. After positioning, the guns are fired under overbalanced condition.

The principle feature of this technique are large diameter casing gun can be used and need no sub-surface pressure control equipment. The disadvantages are poor clean-up and results in damage or plugged perforation. Hence, additional perforation clean-up method must be applied to obtain an effective perforated system with maximum number of perforation contributing to flow.

ii) Reverse-pressure or underbalanced perforating

The reverse-pressure perforating is a technique of perforating the well casing with well pressure less than the formation pressure. Three rather different techniques are in use :

- a) The wireline through-tubing technique
- b) The tubing-conveyed technique and
- c) The hybrid surge technique

a) Wireline through-tubing technique

As implied, small diameter guns are run through the tubing, located as to depth by means of gamma-ray tools and magnetic casing collar locators, and fired under conditions of reverse pressure as shown in fig. 1(b).

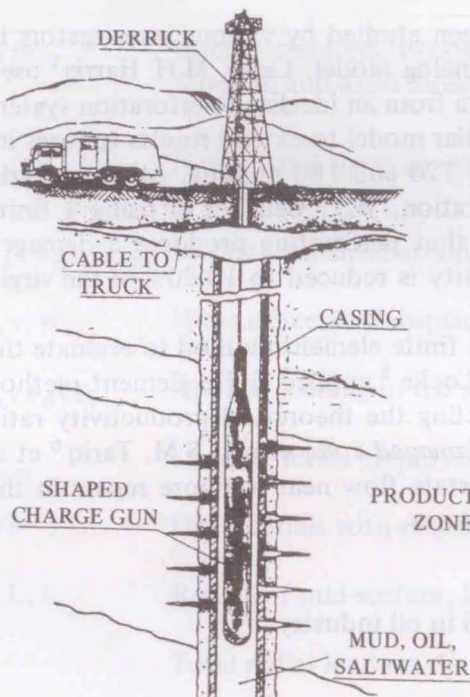


Figure 1 (a) Positive pressure method

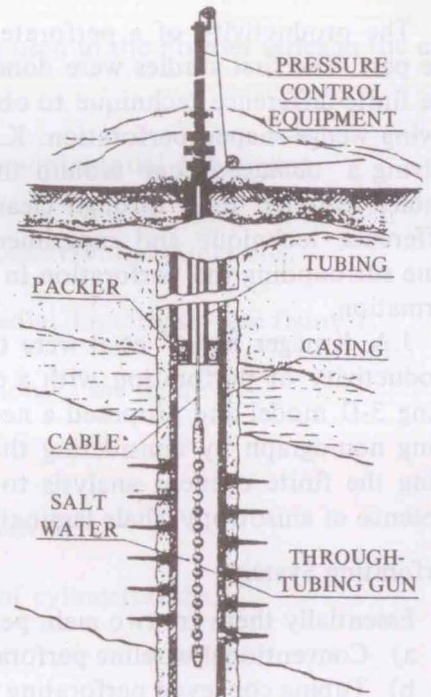


Figure 1 (b) Wire-line through tubing method

This technique of perforating obtains an effective clean-up and remove plugging, but need subsurface pressure-control equipment such as tubing, packer, wellhead, flowline and cannot introduce large diameter gun into the well. There is also a risk of blowing the gun up the well and causing a fishing job under very high differential pressure. Since the perforation clean-up is greatly enhanced by perforating under conditions of reverse pressure, a standard guideline of

applying underbalance pressure are as follows :-

	LIQUID	GAS
Higher Permeability (100 md)	200-500 psi	1000-2000 psi
Lower Permeability (100 md)	1000-2000 psi	2000-5000 psi

b) Tubing conveyed perforating technique

This technique involves running a large diameter multiphased gun into the well below the packer on a tubing string. Tubing is run dry or partially filled, to establish the desired level of reverse differential pressure. After the assembly is positioned as to depth by means of wireline collar-locator and gamma-ray or neutron tools, then the guns are fired by dropping a bar onto the firing head located just above the gun section as shown in Fig. 2.

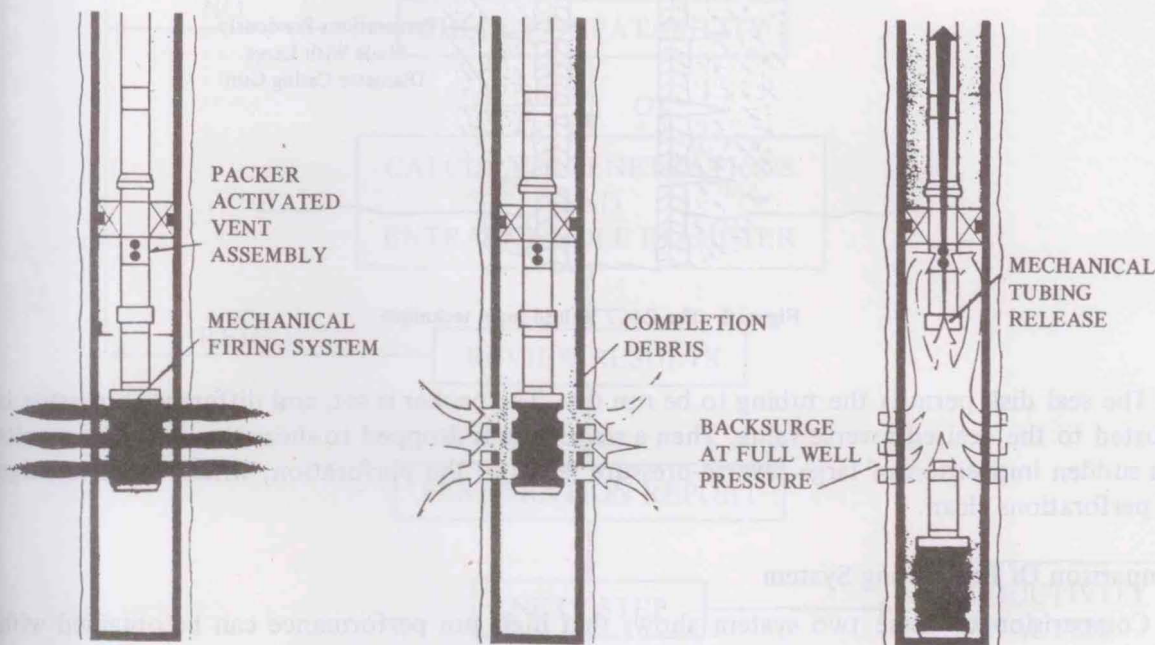


Figure 2 Tubing conveyed perforating technique

Gun usually employed have the same characteristics as those retrievable gun, except that they are large, and therefore offer advantages of greater penetration and multiphasing.

The principle feature of this technique as compared with through-tubing technique are :-

- i) High gun performance
- ii) Higher differential pressure may be used without risk of blowing the gun / cable assembly up the hole.
- iii) Very long intervals or multiple interval can be perforated with one trip, saving valuable rig time.
- iv) Gun can be positioned in highly deviated wells where wireline gun cannot descent.
- v) Can be run below a drill stem test configuration for perforating and formation testing on one trip.

c) The Hybrid surge technique

Another method to improve perforating system is called *PACT (Positive Action Completion Technique)*. This method involves perforating the well conventionally with positive pressure,

using large-diameter casing gun. Then the tubing and packer are run in the hole, with a seal disk installed as shown in Fig. 3.

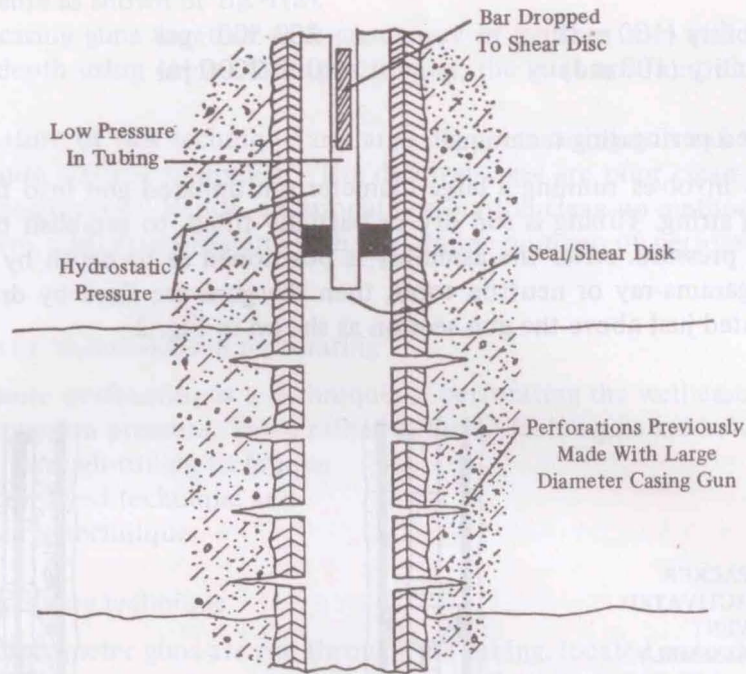


Figure 3 The PACT hybrid surge technique

The seal disk permits the tubing to be run dry. The packer is set, and differential pressure is adjusted to the desired reverse value. Then a sinker bar is dropped to shear the disk. This results in a sudden imposition of large reverse-pressure levels at the perforation, which tends to surge the perforations clean.

Comparison Of Perforating System

Comparison of these two system shows that high gun performance can be obtained with tubing-conveyed perforating system since larger, more powerful charges for more efficient perforations can be used. When long or multiple intervals are to be perforated, the tubing conveyed system with quick make-up intergun connections takes less rig time than conventional wireline system.

Although tubing conveyed perforating system offers many advantages over wireline perforating system, the limitation being the cost and operational consideration. The cost is normally about 25 % greater than wireline system. But the benefit it gains with high gun performance and less damaging completion could actually result in lower overall completion costs generally – not to mention consistently better well performance. Whatever it is, the choices of system used are dependent on the type of well completion and are constrained by the well configuration, wellbore fluid pressure, formation characteristics and damage conditions.

The wireline perforating system is still preferred by most of the operators. The tubing conveyed perforating system is only considered in some cases where wireline system cannot perform well or the total perforating cost is slightly more or equal.

The SPANOIL Programme

The Schlumberger *SPANOIL* consists of two module which may be used separately or in combination. The first module calculates the shaped charge's penetration and entrance hole diameter using tabular data, hole size and the properties of the various layers the jet encounters.

The second module uses previously computed penetration and entrance-hole data or perforation characteristics input by the user plus the completion scheme and reservoir parameters to predict productivity ratio and skin factors resulting from perforations. The relationship between these two modules at various points during the execution of *SPANOIL* are shown in Fig. 4 and Fig. 5.

17A
18A

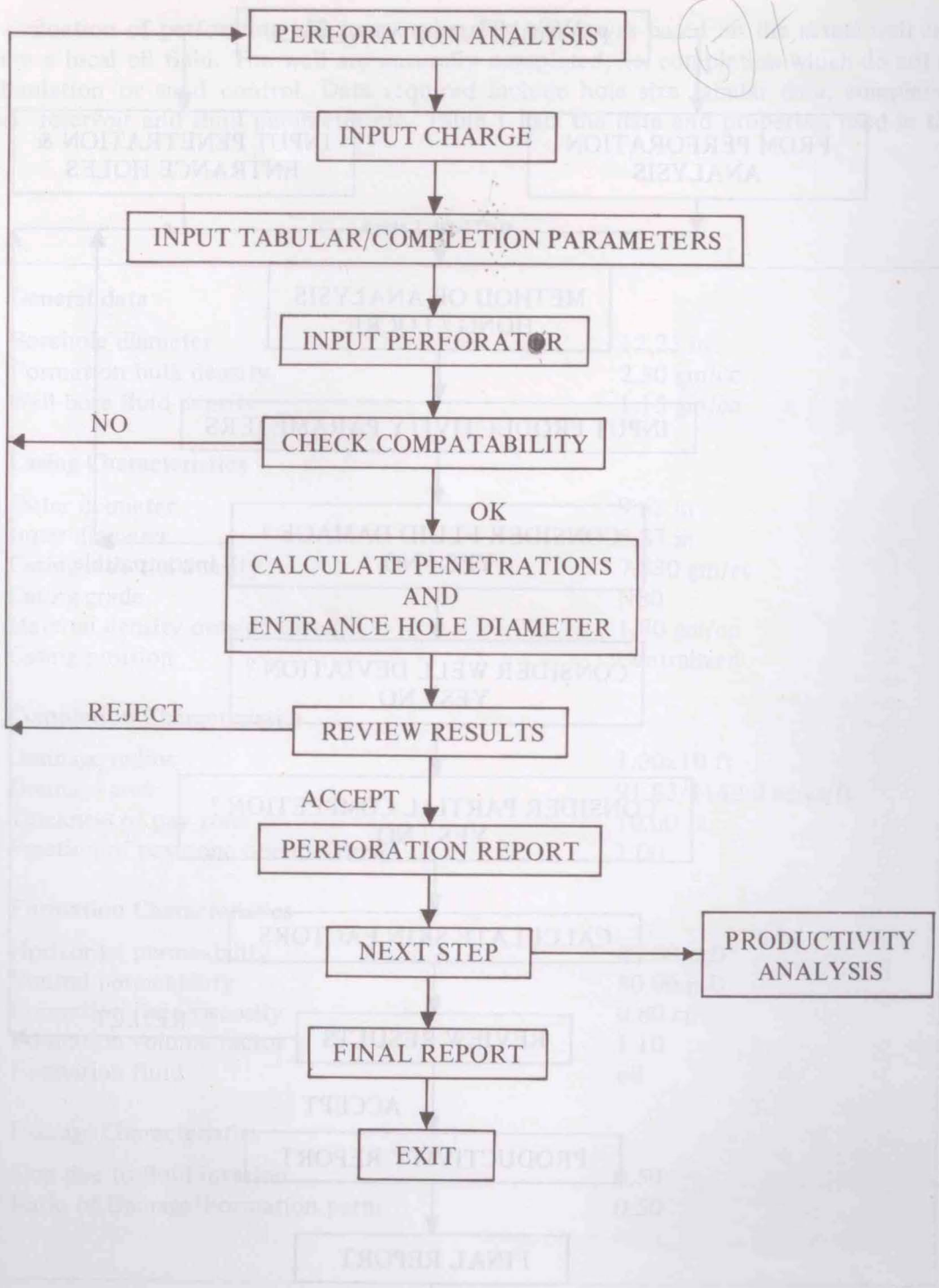


Figure 4 Flow Chart of SPANFIL Perforation Analysis

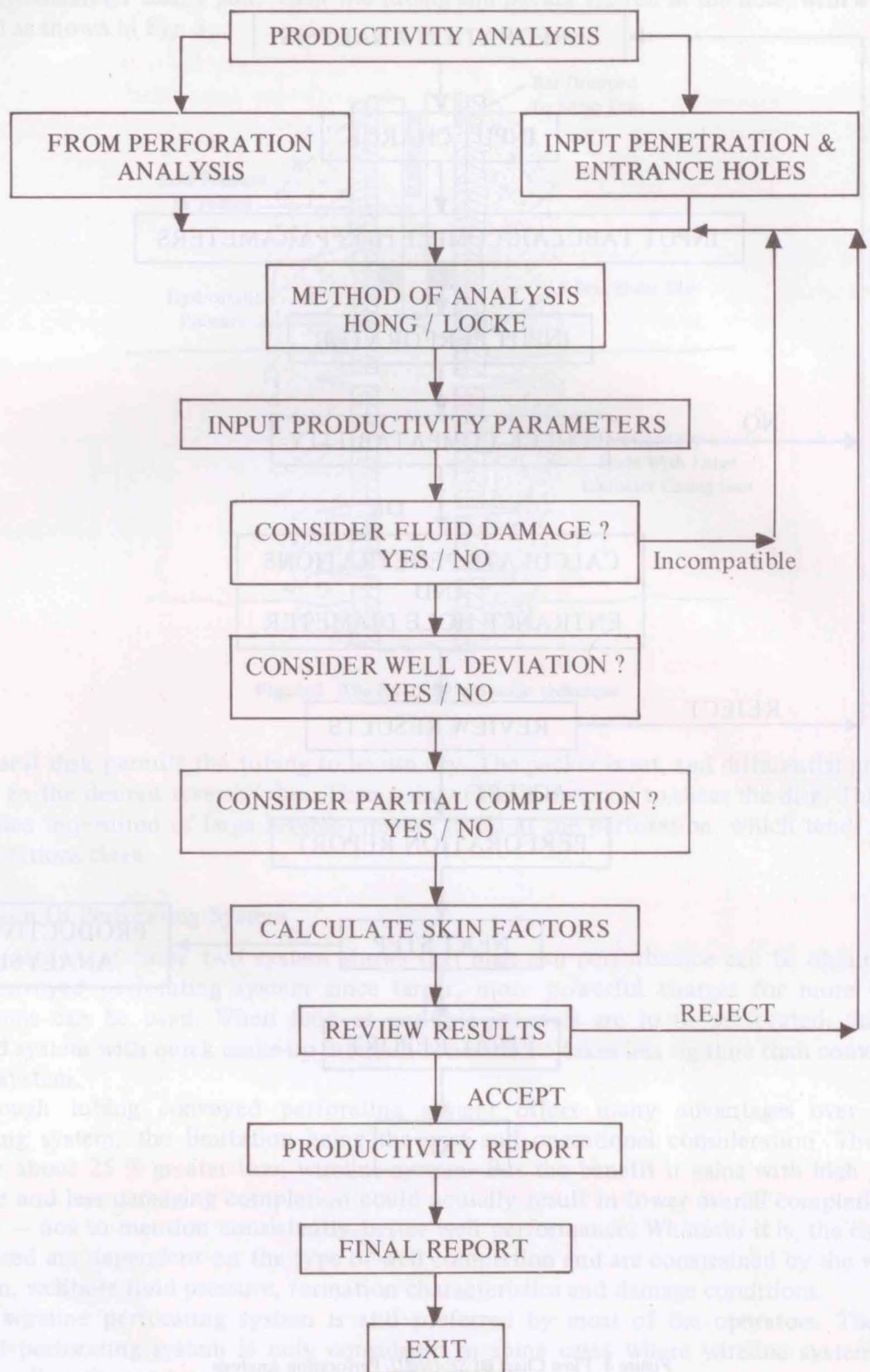


Figure 5 Flow Chart Of SPANOIL Productivity Analysis

Data base

The evaluation of perforating efficiency using *SPANOIL* was based on the actual well data taken from a local oil field. The well are naturally completed; i.e., completion which do not involve stimulation or sand control. Data required include hole size tabular data, completion characters, reservoir and fluid parameter etc. Table 1 lists the data and properties used in this study.

Table 1 Well Data

General data	
Borehole diameter	12.25 in
Formation bulk density	2.30 gm/cc
Well-bore fluid density	1.15 gm/cc
Casing Characteristics	
Outer diameter	9.63 in
Inner diameter	8.83 in
Casing material density	7.830 gm/cc
Casing grade	N80
Material density outside casing	1.80 gm/cc
Casing position	Centralized
Completion Characteristics	
Drainage radius	1.00x10 ft
Drainage area	91.83/1142.0 acres/ft
Thickness of pay zone	10.00 ft
Fraction of pay zone open to flow	1.00
Formation Characteristics	
Horizontal permeability	80.00 mD
Ventral permeability	80.00 mD
Formation fluid viscosity	0.80 cp
Formation volume factor	1.10
Formation fluid	oil
Damage Characteristics	
Skin due to fluid invasion	0.50
Ratio of Damage/Formation perm	0.50

Five different types of shaped charges with various shot density and phasing are simulated under the same well condition. The five types of shaped charges employed are:-

- a) For through-tubing perforating (Fig. 6)
- i. 1 3/8", 1 11/16", 2 1/8" and 2 7/8" Hyperdome (*Scallop Gun*) with 0 deg phasing and 2, 4, 6, 8 shots/foot.
 - ii. 1 11/16" and 2 1/8" Enerjet (*Enerjet Gun*) with 0 deg phasing and 2, 4, 6, 8 shots/foot.

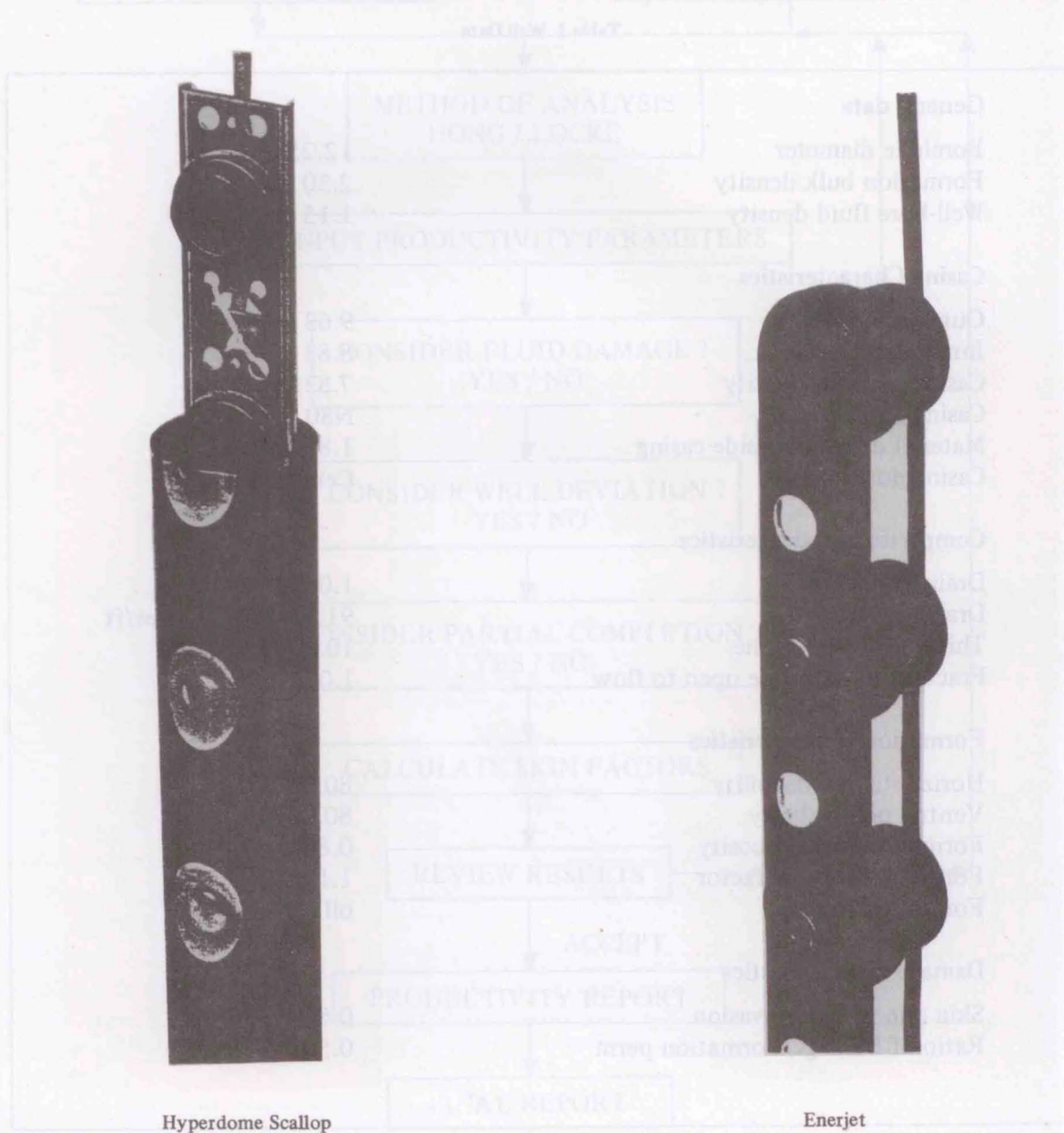


Figure 6 Guns for through-tubing operation

b) For casing perforating (Fig. 7)

- i. 3 3/8", 4" and 5" (37 gm) Hyperjet II (*Hollow carrier gun*) with 90 deg phasing and 2, 4, 8, 10, 12 shots/foot.
- ii. 5", 5.5", 6" and 7.25" HSD Hyperjet II (*High-shot density gun*) with 120 deg phasing and 3, 6, 9, 12 shots/foot.
- iii. 5", 5.5" and 6" HSD (4" ultrapack) (*High shots density gun*) with 120 deg phasing and 3, 6, 9, 12 shots/foot.

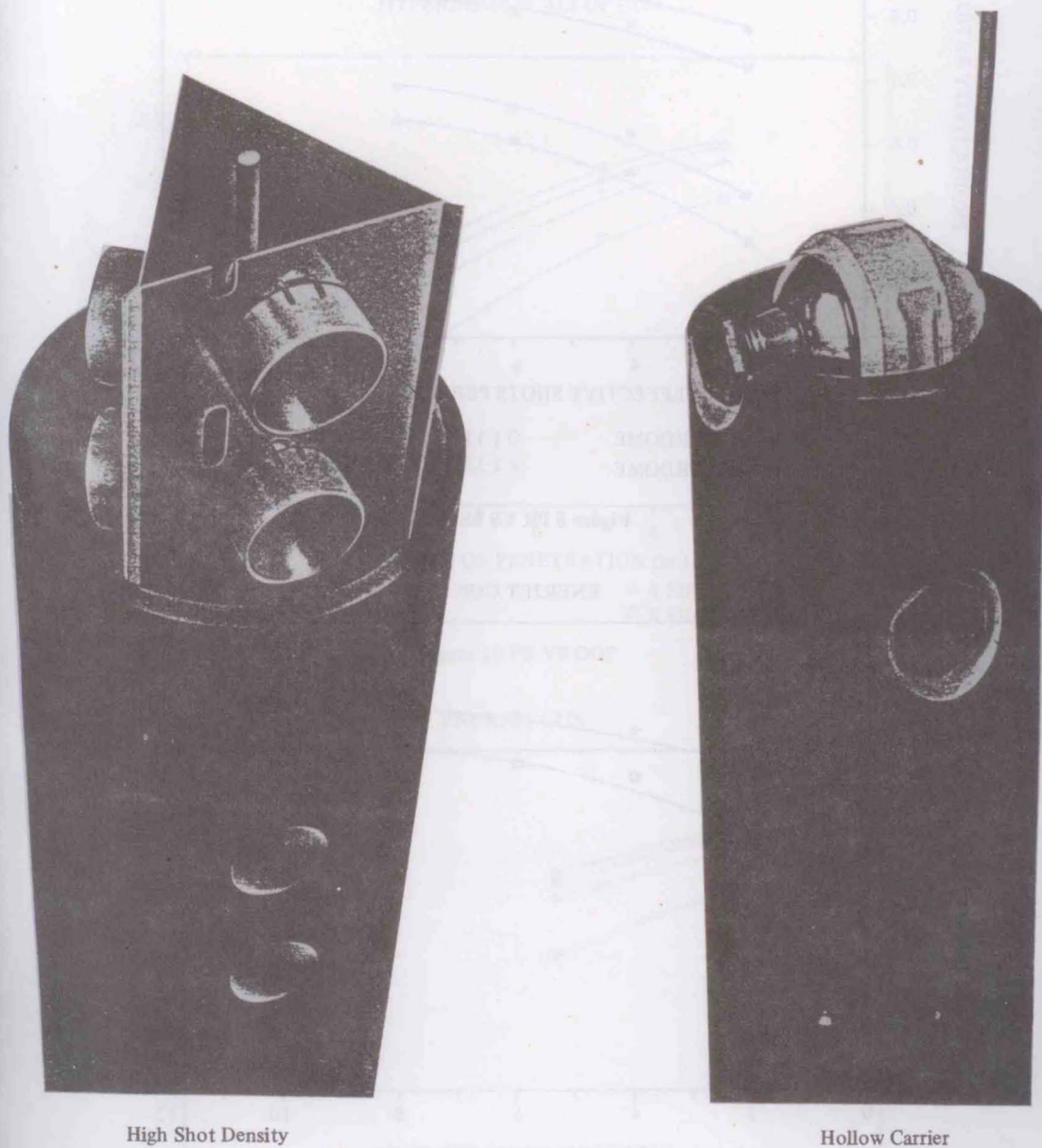


Figure 7 Guns for casing operation

Results

All the results obtained are presented in terms of productivity ratio; which is the ratio of the steady-state flow rate for the perforated completion to the openhole flowrate for various combination of perforating parameters.

Discussion of results

a) For through-tubing perforating

Fig. 8 and Fig. 9 show the effect of varying shot density on productivity ratio for two types

of through-tubing guns — Hyperdome Scallop and Enerjet. The densities shown are 2, 4, 6, 8 shots/foot. It is obvious that the increase in shot density will increase the productivity ratio

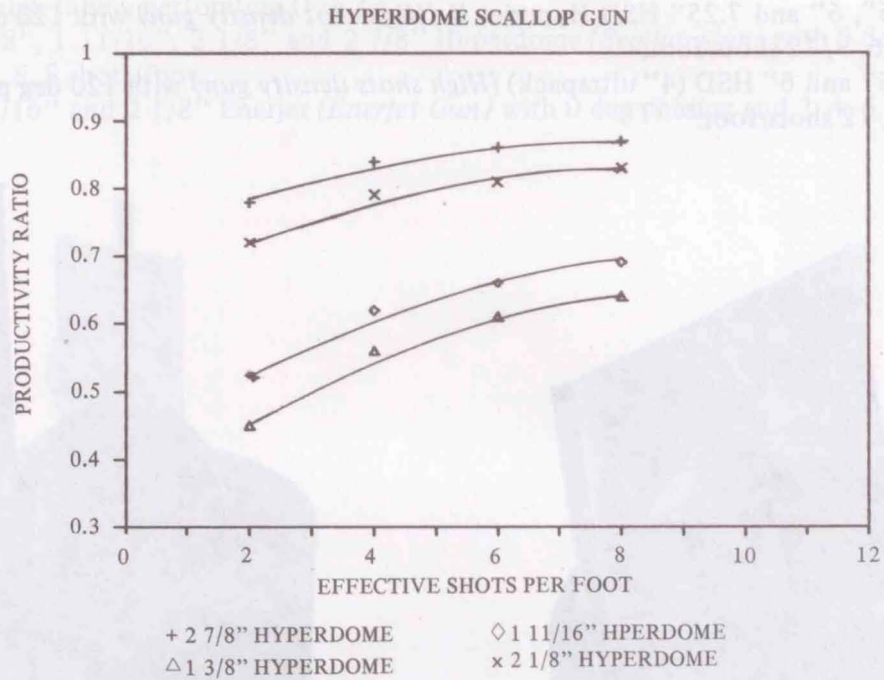


Figure 8 PR VS ESPF

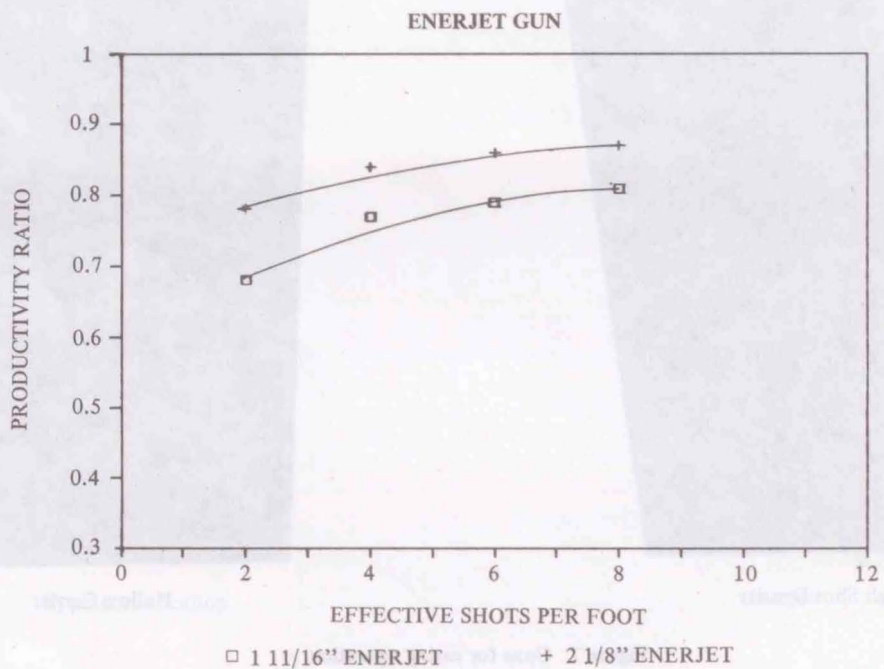


Figure 9 PR VS ESPF

From Fig. 8, the 1 11/16" and 1 3/8" Hyperdome show a very poor productivity ratio which ranges from 0.45 to 0.65. The increase is rather substantial at 2 1/8" and 2 7/8" charges. An approximately of 20% improvement in productivity is observed for 2 1/8" commencing from 1 11/16" Hyperdome charges. The 2 7/8" charge shows the best performance with productivity ratio ranges from 0.78 to 0.86.

From the comparison of Fig. 8 and Fig. 9, it can be seen that for the same size of gun (1 11/16" and 2 1/8"0, the Enerjet charge proved excellent with approximately 20% and 8% improvement over Hyperdome charge. The 2 1/8" Enerjet charge performs as well as 2 7/8" Hyperdome charge with productivity ratio ranges from 0.78 to 0.87.

Fig. 10 and Fig. 11 show additional comparison of the two charges. As shown, the productivity increases with depth of penetration. The increase is rather substantial at small penetrations (ie 2 to 6 in). At larger perforation penetrations, the increase in productivity is less, but the trend is toward continuing improvement in productivity with increase in perforation penetration. The productivity increases substantially from 2 to 6 shot/foot, but tends to flatten out beyond 6 shots/foot.

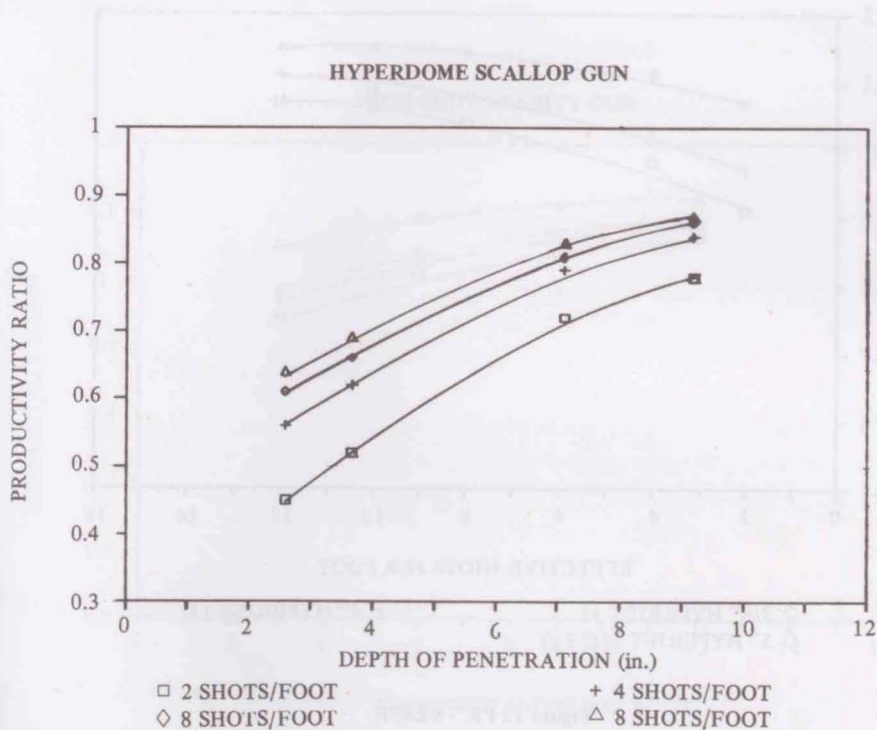


Figure 10 PR VS DOP

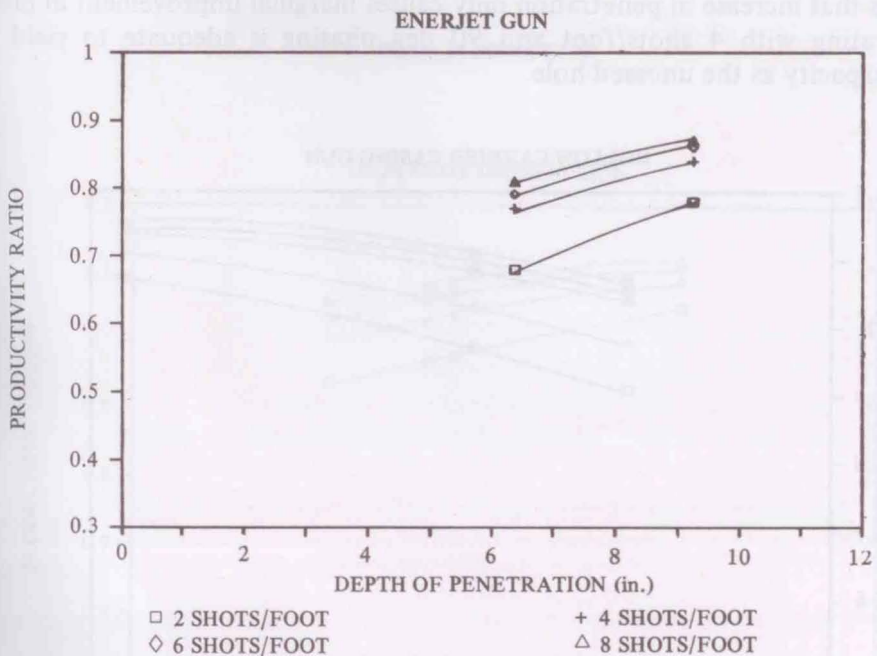


Figure 11 PR VS DOP

) For casing perforating

Casing perforating utilizes large diameter gun to perforate in open casing. Both tubing conveyed and wireline system are available for Standard Hollow Carrier and High Shot Density Gun. Fig. 12 to Fig. 17 present the effect of varying shot density and penetration length on productivity ratio for various sizes of casing guns. The types of charges used are Hyperjet II, MSD Hyperjet II and HSD (4" Ultrajet).

Fig. 12 shows that for perforating with 3 3/8" and 4" Hyperjet II charges with 8 and 4 shots/foot respectively is sufficient to achieve the same productivity for the open hole condition. The 5" Hyperjet (37 g) charge is superior in maximizing the well productivity. There is no increase in productivity beyond 8 shots/foot for this charge.

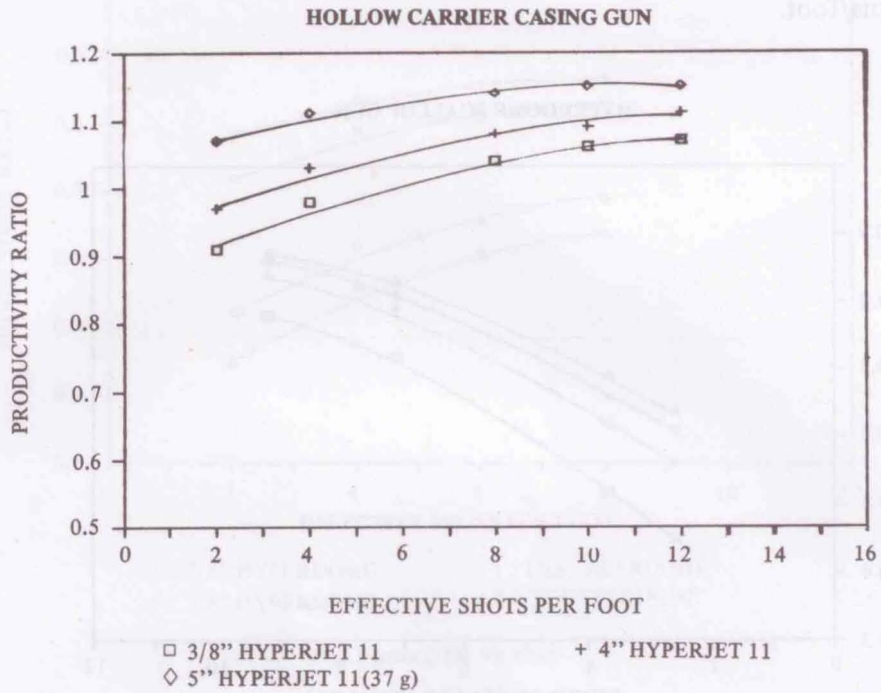


Figure 12 PR VS ESPF

Fig. 13 shows that increase in penetration only causes marginal improvement in productivity ratio and perforating with 4 shots/foot and 90 deg phasing is adequate to yield the same theoretical flow capacity as the uncased hole.

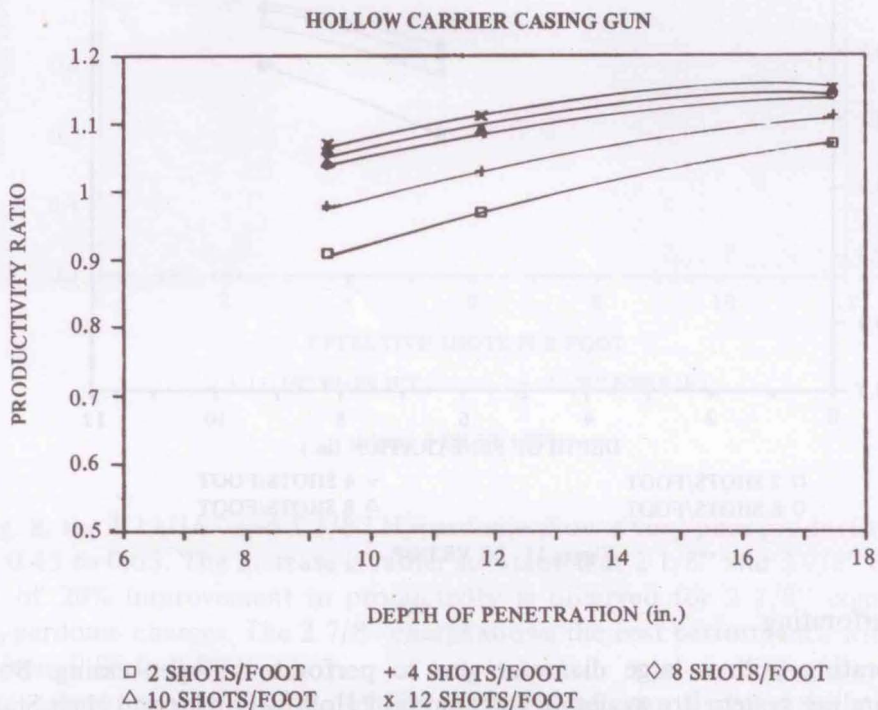


Figure 13 PR VS DOP

Fig. 14 and Fig. 15 indicate that, at a shot density of 6 shots/foot, an average perforation length of 9 in. at 120 deg phasing for 5" HSD HJ II charge is sufficient to achieve productivity ratio to 1.0. Perforating with larger charges only causes a marginal improvement in productivity.

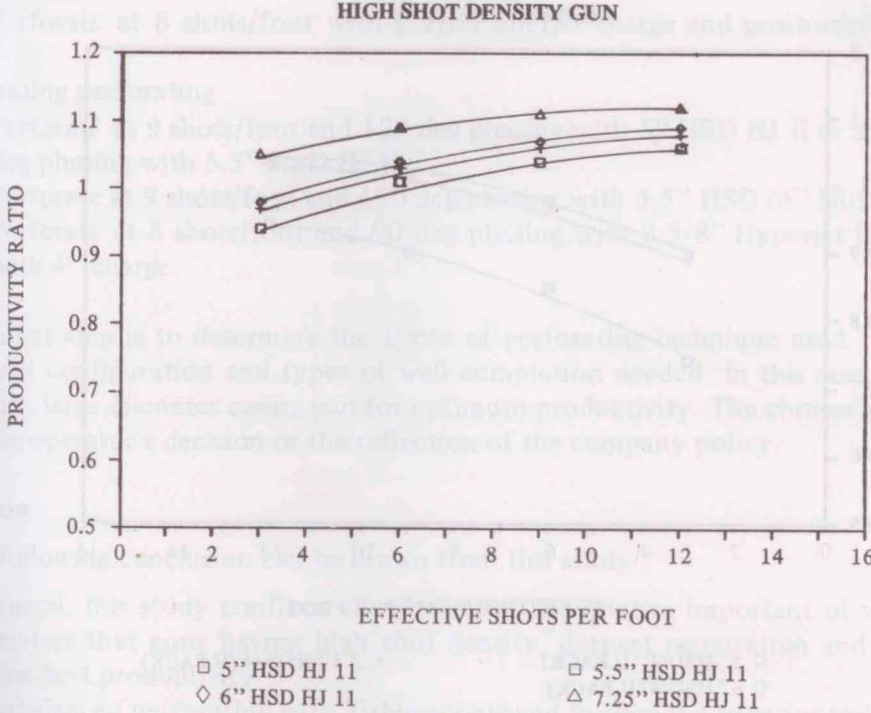


Figure 14 PR VS ESPF

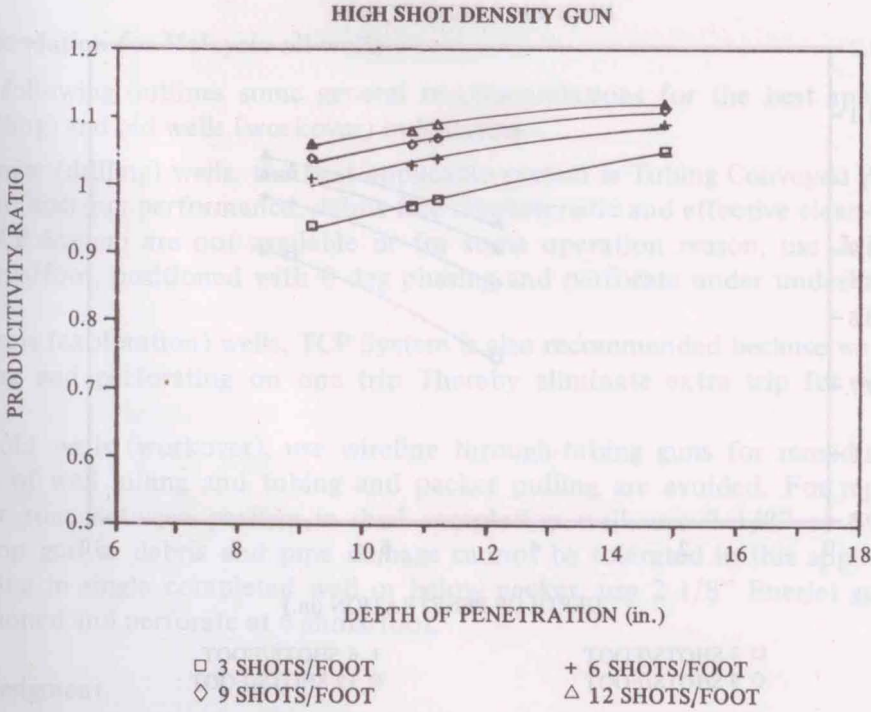


Figure 15 PR VS DOP

Fig. 16 shows that an approximately 20% improvement in productivity can be obtained by perforating with 5.5" HSD (4" Ultrapak) charge instead of 5". There is nearly no increase in productivity for larger charge (6") with the same shot density. Fig. 17 indicates, perforating with 12 shots/foot utilizes 5.5" HSD (4" Ultrapak) charge will give the same productivity as open hole condition.

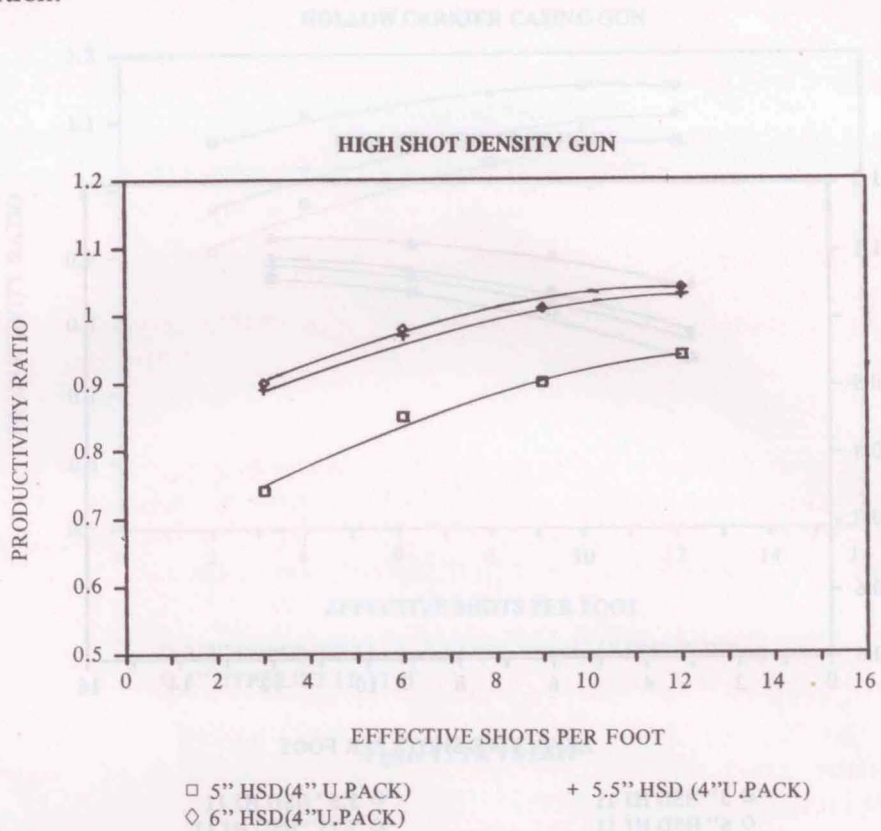
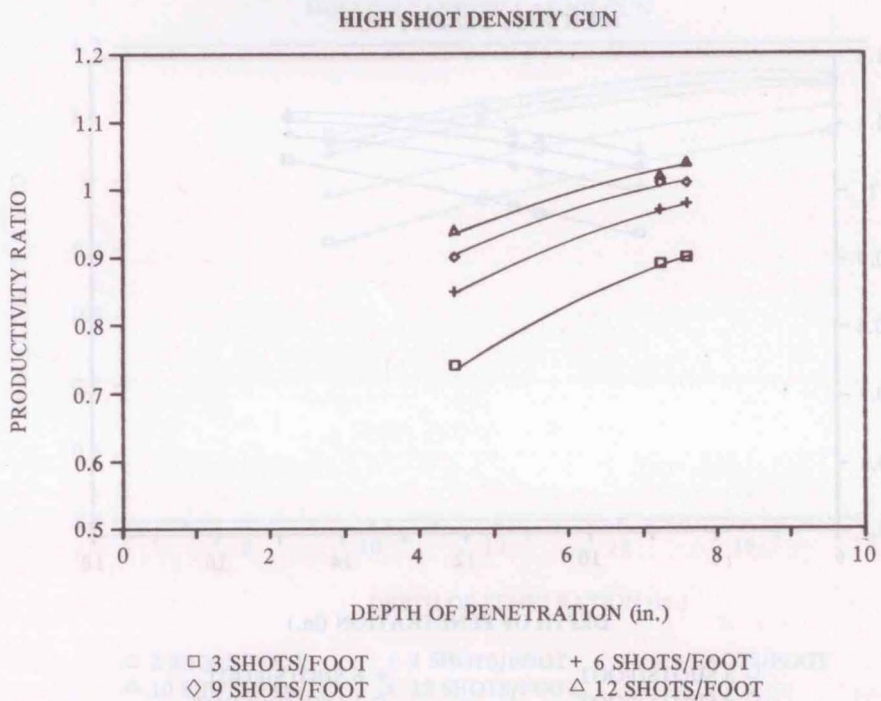


Figure 16 PR VS ESPF



Decision making

After the performance of all charges had been analysed. We come to a important state of decision making – to choose the right perforator under the existing condition. The preliminary selection of the charges are as follow:

- a) For through tubing perforating
 - i) Perforate at 8 shot/foot with 2 7/8" Hyperdome and positioned the charge at 0 deg phasing.
 - ii) Perforate at 8 shots/foot with 2 1/8.. Enerjet charge and positioned at 0 deg phasing.
- b) For casing perforating
 - i) Perforate at 9 shots/foot and 120 deg phasing with 5" HSD HJ II or at 6 shots/foot, 120 deg phasing with 5.5" HSD HJ II
 - ii) Perforate at 9 shots/foot and 120 deg phasing with 5.5" HSD (4" UltraPack)
 - iii) Perforate at 8 shots/foot and 90 deg phasing with 3 3/8" Hyperjet II or at 4 shots/foot with 4" charge.

The next step is to determine the types of perforating technique used. This is constrained by the well configuration and types of well completion needed. In this case, it is better to perforate with large diameter casing gun for optimum productivity. The choices of the charge to be used is the operator's decision or the reflection of the company policy.

Conclusion

The following conclusion can be drawn from this study ;

- 1) In general, this study confirms the finding of the relative important of various perforating parameters that guns having high shot density, deepest penetration and best phased angle give the best productivity.
- 2) Underbalanced perforating with Tubing-conveyed System is a superior technique.
- 3) The selection of charges used is dependent on well condition, wellbore fluid type, pressure, temperature and mechanical requirements.
- 4) The choice of equipment and technique should balance the operating cost, perforation performance and mechanical aspects.

Recommendation for Malaysia oil wells

The following outlines some general recommendations for the best applicable system for new (drilling) and old wells (workover) in Malaysia.

- 1) For new (drilling) wells, the best applicable system is Tubing Conveyed Perforating System due to high gun performance, debris free characteristic and effective clean-up.
If TCP System are not available or for some operation reason, use 2 1/8" Enerjet with 6 shots/foot, positioned with 0 deg phasing and perforate under underbalanced condition.
- 2) For new (exploration) wells, TCP System is also recommended because we can combine well testing and perforating on one trip Thereby eliminate extra trip for wireline operation.
- 3) For old wells (workover), use wireline through-tubing guns for remedial operation since costs of well killing and tubing and packer pulling are avoided. For reperforation of the upper zone between packers in dual completion well, use 2 1/8" or 2 7/8" Hyperdome Scallop gun as debris and pipe damage cannot be tolerated in this application. For reperforating in single completed well or below packer, use 2 1/8" Enerjet gun. Gun chosen is positioned and perforate at 6 shots/foot.

Acknowledgment

The author thanks the Schlumberger company for permission of using the *SPANOIL* software. In addition, assistance provided by Dr. Abu Azam and Aziz Ayob is gratefully acknowledged.

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