UTILIZING PERFORATION PERFORMANCE MODULE (PPM) AND EXTREME UNDER-BALANCE (EUB) PERFORATING TO MAXIMIZE ASSET VALUE IN DEEP LOW POROSITY - LOW PERMEABILITY GAS RESERVOIRS – A CASE STUDY FROM INDONESIA

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PROPOSAL

VICO Indonesia is an Oil and Gas Company operating the Sanga-Sanga PSC in East Kalimantan. There are four operating assets: Nilam, Mutiara, Semberah, and Badak. The depositional environment consists of fluvial-deltaic sands with oil and gas bearing sandstone formations stacked on top of each other; there are on average ten to twenty zones per well. The primary objectives for the Vico asset team is to exploit these reservoirs to their maximum potential to meet the gas delivery to the Bontang LNG plant and to maximize asset value by increasing production with a lower investment.

In order to achieve the above objective at optimal cost, much emphasis is being given to rigless activities. The main activity is to open these stacked gas-bearing sandstone formations by adding perforation either by wireline or by using extreme under-balanced perforating techniques.

This paper focuses on the use of a state-of-the-art software perforation performance module (PPM) in conjunction with extreme under balanced (EUB) perforating techniques for maximizing gas production from the deep low-permeability and low-porosity gas-bearing reservoirs. This paper presents various cases showing how effectively and economically these deep sandstone formations can be completed to maximize the return on investment (ROI). The Perforation Performance Module (PPM) was used to predict potential performance from these reservoirs. The actual post-job results were then used to verify the predictions. This was done primarily to assist VICO in making the decisions in line with the economic benefits for various perforating techniques.

RESERVOIR DESCRIPTION

VICO Indonesia's Oil and gas fields are located in the Kutai Basin, East Kalimantan, shown in **Figure 1**. The sedimentary system covers the time frame beginning from the Miocene age. At the end of the Miocene period, the ancient delta, which moved from west to east, was formed. The Delta uplift created folds. Two of the most common sandstone facies recognized in the Miocene sediments are fluvially dominated, distributary channeled, and tidally dominated delta front bar deposits. Commercial hydrocarbons can be produced from highly quartzitic channel sandstone to a maximum depth of burial of 15,000 ft. In general, distributary channel facies have a relatively higher porosity compared to a front bar.

The sedimentary system is divided into three sequences. The upper and middle sequences have good reservoir quality (porosity and permeability), while the lower sequence has poorer reservoir quality. The lower sequence (deep gas sand), which exists in all VICO fields, offers a significant volume of gas to be exploited. From the petrophysical calculation, permeability is less than 5 md, and porosity is less than 12% while the pressure is slightly overpressured.

COMPLETION PHILOSOPHY

Until 1997, VICO was completing these wells with multiple packers and dual strings with sliding sleeve circulating devices in the string. This resulted in increased workover complexity. As the fields were maturing, the simple dual-tubing-string completion first used was no longer adequate to provide the required gas deliverability. Conventional dual selective dual completions were then deployed. This design had some significant advantages over the simple dual. The main advantage was capability to perform one workover or completion and develop numerous reservoirs at the same time. However, there were also disadvantages. These completions are mechanically complicated and have many sealing areas. Therefore, the dual selective completion is susceptible to failure. The cost of failure can be a workover, or in some cases, the loss of the bottom part of the completion. Several detailed studies were conducted to determine methods to improve completion reliability, and improvements were continuously implemented. However, the completions were still very complex and expensive. **Figures 2** and **3** are examples of conventional dual completions and conventional dual selective completions.

In order to maximize the technical efficiencies and improve the ROI, other completion philosophies were reviewed by VICO.[4] As a result of the review, the completion technique was altered to employ the following changes:

1. Drill-bit size was changed from 12¼-in. to 8½-in.
2. A 4½-in. monobore production casing was run and cemented. Previously, a 7- or 95/8-in. casing had been used (See **Figure 4**)
3. The gas zones of interest were perforated individually from the bottom zone up using new modified perforating techniques as opposed to traditional tubing-conveyed perforating.

These changes resulted in lower:

1. *Capex* due to a reduction in ancillary equipment; i.e., packer, tubing and flow control equipment were not used in the new completions.
2. *Opex* as a result of reduced complexity during the workover operations.

PERFORATING TECHNIQUE

During underbalanced perforating, the pressure in the wellbore is lower than the pressure in the formation. The level of pressure differential is important to create open, undamaged perforations and to optimize well productivity. VICO has been perforating these deep sandstone formations using EUB perforating procedures. This perforating technique is executed with virtually no hydrostatic pressure on the formation. This has made dramatic improvements in the productivity of the well. The 5-fold increase in Mcf/D and md-ft using the EUB approach is very encouraging.[2] It has also been shown that perforating with large underbalance has not made a large difference in formations that have good permeability. The zones that VICO perforates are highly consolidated, and sand production is not a problem. VICO has successfully perforated intervals with underbalance ranging from 2100 to 4700 psi.

Since the completion philosophy has been for monobore wells, it is easier to perforate EUB. The casing is unloaded to a point with approximately 100 feet of brine in the well. The brine acts as a shock absorber when the guns are fired, so that they do not part. A simple tubing stop is run on slickline and set at the desired depth. A stump gun is run and set on top of the tubing stop. The stump gun is a standard perforating gun with the scallops drilled out. The purpose of the stump gun is twofold;

1. It allows minor adjustments in the perforating depth to be made by increasing or decreasing the length of the perforating gun
2. It provides a path for any perforating debris because the scallops are drilled out.

Modular guns are stacked on top of the tubing stop using slickline.

The modular guns are run on slickline in the unperforated monobore, which is near liquid free. Each gun module consists of the perforating carrier with a skirt on bottom that fits over a stinger on the previously run module. This provides a series of interconnected modules to be fired simultaneously. After the guns are fired, each module is retrieved from the monobore with slickline without killing the well. Details are shown in **Figure 5**.

PERFORATION PERFORMANCE MODULE (PPM)

The PPM process employs state-of-the-art perforation design software and a global perforation efficiency database, which was developed in the perforation-flow laboratory of a major oilfield service company. **Figure 6** illustrates the PPM workflow process. This unique combination enables operators to maximize production by quantitatively determining a well's optimum perforating design. The process works by simulating a wide range of well conditions and flow measurement options in low-permeability hard rock and high-permeability unconsolidated sandstone.

Recent experiments by Folse et al[1] at the developer's perforation flow laboratory highlight the importance of optimizing the degree of underbalanced pressure. Underbalanced perforating creates negative differential across the formation during the perforation, offering significant benefits. Maximum perforation cleanup can be applied to the entire perforation interval from the surge effect with no fluid invasion into the reservoir. The two photos in **Figure 7** show the results of the lab work on two cores from the same formation. These cores are perforated at different degrees of underbalance. Upon retrieving the cores from the test cell, they were cut and filled with eutectic material. Core shot at balanced condition showed 14-in. of penetration; however, only 50% of that was contributed to the flow as the remaining 50% contained a crushed and pulverized zone. As can be seen, the rock shot with an underbalance shows a 15-in. penetration with the entire 100% of the rock contributing to the production. Upon performing the flow test through the core, an 82% increase in productivity in the core that was shot 3500 psi underbalance was shown. This is a result of the cleaner perforation tunnels obtained as a result of the underbalance perforating.

Based on Folse's laboratory experiments, a PPM was developed. This PPM has a systematic approach to optimize well inflow performance by proper selection of the gun system, charge type, shot density, phasing, conveyance method, and well condition (overbalanced or underbalanced pressure). The PPM software is a web-based application that analyzes the effects of downhole conditions on perforator performance and productivity. The PPM program performs calculations for charge performance (formation penetration and perforation hole diameter) and well productivity (productivity index and total skin). The PPM workflow is designed to provide optimum perforating conditions and prediction of gun-system performance.

Case Study 1:

This well was located in the Mutiara field. This well was drilled and completed as a 4.5-in. monobore. (See **Figure 8** for more details. The zone of interest was at the bottom section of the well. The reservoir and the wellbore details are provided in **Table 1**.

The data was used as described above in case 1 to provide the perforation performance. The perforation performance of different perforating techniques and perforators were evaluated. Wireline guns in underbalanced conditions versus TCP 2-3/4-in., 2 ½-in. and 3 3/8-in. guns using EUB were compared. The inflow performance results of two perforating techniques and four perforators are shown in **Figure 9**. A complete economic evaluation of the operation was performed, and results are shown in **Figure 10**. The option with the higher return could not be deployed because of the unavailability of that equipment in Indonesia

Case Study 2:

This well was located in the Nilam field. This well was recompleted as a 4.5-in. monobore. This well had a special challenge since the reservoir had to be accessed through three sets of casings in the recompletion. (See **Figure 11** for more details.) The zone of interest was in the lower-middle section of the well. The reservoir and the wellbore details are provided in **Table 2.** The reservoir parameters were reasonable, but the challenge was to access them through three sets of casing strings.

A detailed examination of all the available data were input into the PPM. Different perforating techniques and perforators were evaluated. Three types of TCP guns using EUB technique, 2-3/4-in., 2-½-in. and 3-3/8-in. respectively, were compared with the wireline perforating technique. The comparison was then used to perform complete IPR and VLP analyses, the results of which are shown in **Figure 12**.

A detailed economic feasibility of the entire operation was conducted. Economic evaluation, shown in **Figure 13**, for different perforating techniques and perforators was performed in order to be able to select the optimum perforator and technique. As in Case 1, the first option could not be exercised due to the unavailability of the equipment.

VALUE ADDITION AND ANALYSIS OF POPULATED DATA

The introduction of PPM to VICO enabled better production forecasting, and in conjunction with the economic analysis, proved to be a good tool. It assisted the VICO engineers in making the decision to deploy a different perforating technique and perforators.

To date, numerous cases have been performed, and 17 cases were documented. **Figure 14,** which shows the predicted Vs actual results, illustrates the reliability of the PPM. It is essential for the reader to bear in mind that quality control of the PPM input data is imperative if results are to be used effectively for influencing operating decisions.

RESULTS, OBSERVATIONS AND CONCLUSIONS

The success in the EUB perforating performance and the capability of the PPM software module to accurately predict well deliverability has increased VICO's confidence in the application of this particular software to assist in effective candidate selection. The predictions from the PPM were within ±10% of the actual post job results.

In the high-permeability zones, the log-derived permeability data is not as efficient as that retrieved from the tight gas sands. One of the reasons for this difference is that the sands are prolific and known to produce at very high rates. As a result, the PPM model was capable of predicting the results in the tight sands with greater accuracy than the results in the high permeability regions.

APPLICATIONS

This EUB perforating technique has proven to be effective in the deep, low-porosity- and low-to-medium-permeability formations where sand production is not an issue. The PPM can be effectively used in predicting the perforation performance in any scenario if there is adequate information available concerning the reservoir rock properties and fluid properties.

REFERENCES

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4.) George Dyer, G., Ismanto, B., and Hass, M.: "New Well Architecture Successfully Optimizes the Development of Fluvio-Deltaic Multi-Layered Gas Field" SPE paper 64394 presented at the SPE Asia Pacific Oil and Gas Conference and Exhibition held in Brisbane, Australia 16-18 October 2000.

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Table 1
Wellbore and Reservoir Properties

Item	Wellbore & Reservoir Parameters	Value
1	Perforated Interval	7784' – 7818'
2	Borehole Diameter	8 ½-in.
3	Casing Size	4 ½-in. 11.6 lb/ft
4	Reservoir Pressure	3349 psi
5	Reservoir Temperature	225 deg F
6	Porosity	13%
7	Permeability	11.6 md

Table 2
Wellbore and Reservoir Properties

Item	Wellbore & Reservoir Parameter	Value
1	Perforated Interval	10786' – 10792'
2	Borehole Diameter	12 1/4-in.
3	Casing Size	9 5/8-in. 47 lb/ft 7-in. 29 lb/ft 4 ½-in. 11.6 lb/ft
4	Reservoir Pressure	3378 psi
5	Reservoir Temperature	280 deg F
6	Porosity	20%
7	Permeability	130 md

Semberah

Badak

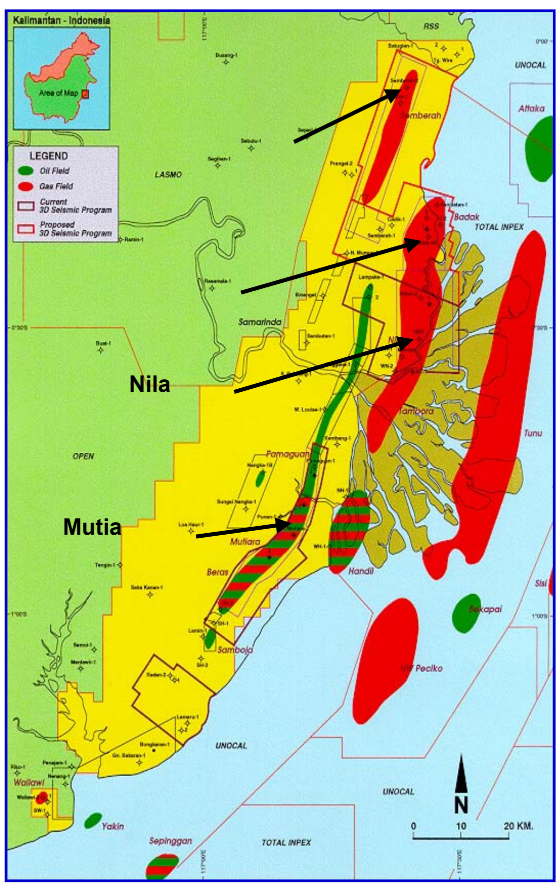

Figure 1 - Area of

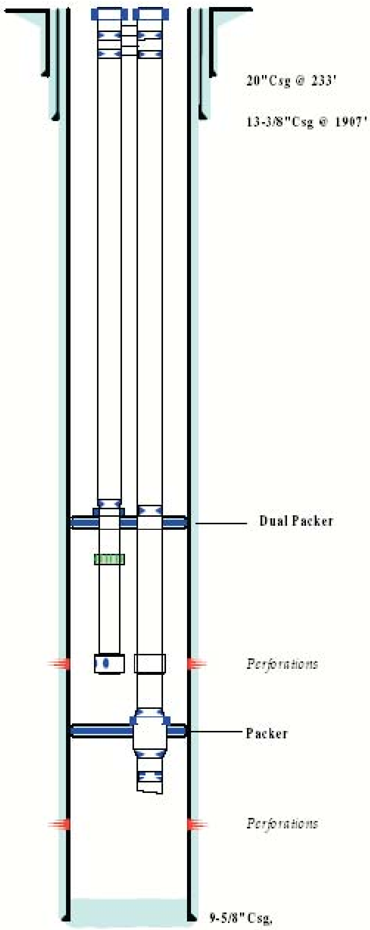

Figure 2 — Conventional Dual Completion

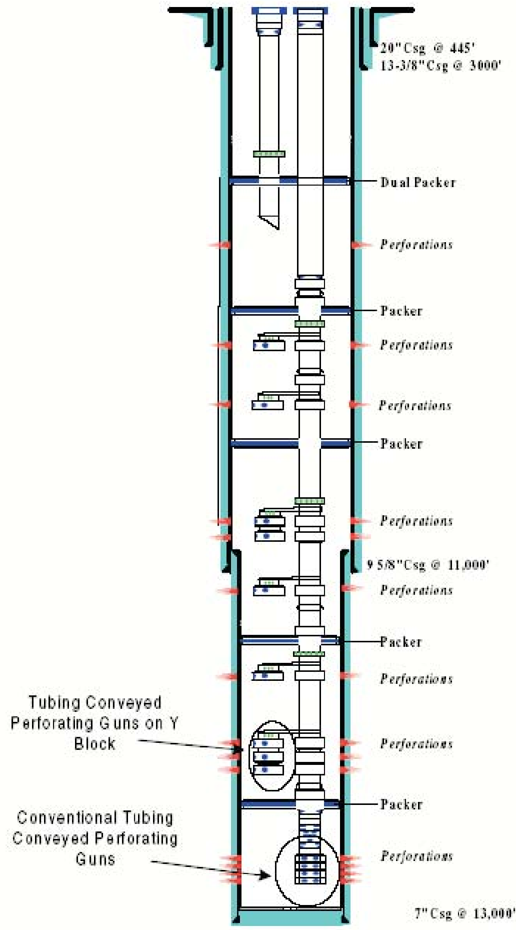

Figure 3 — Conventional Dual Selective Completion

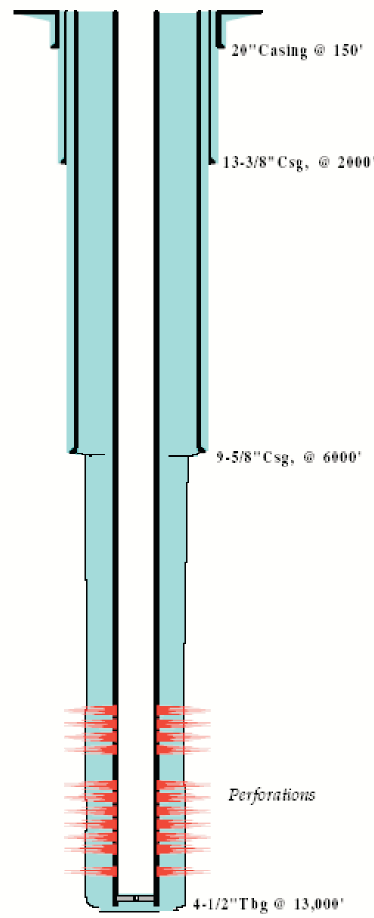

Figure 4 — Monobore Completion

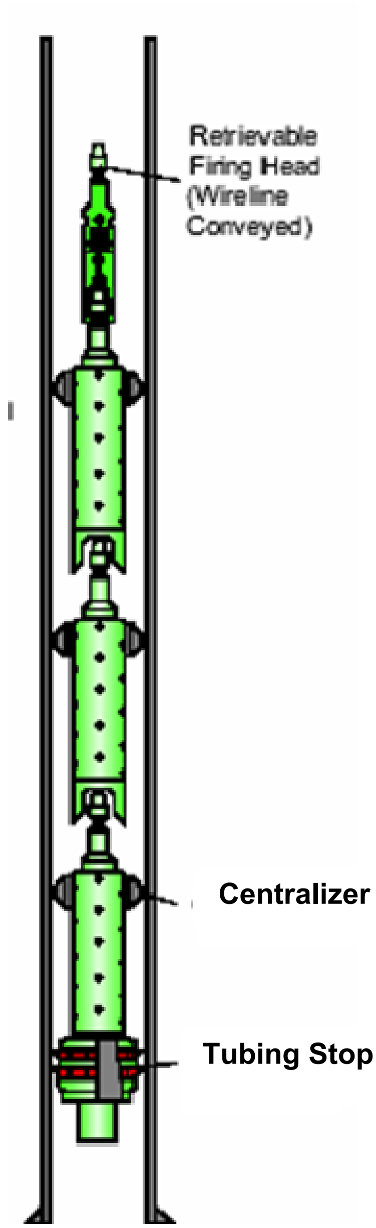

Figure 5 — Modular Gun Installation

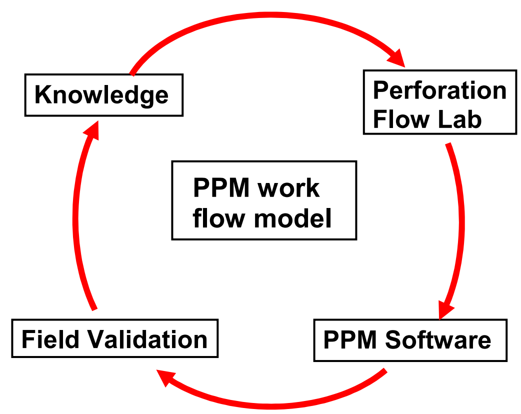

Figure 6 — PPM Work-Flow Model

Figure 7

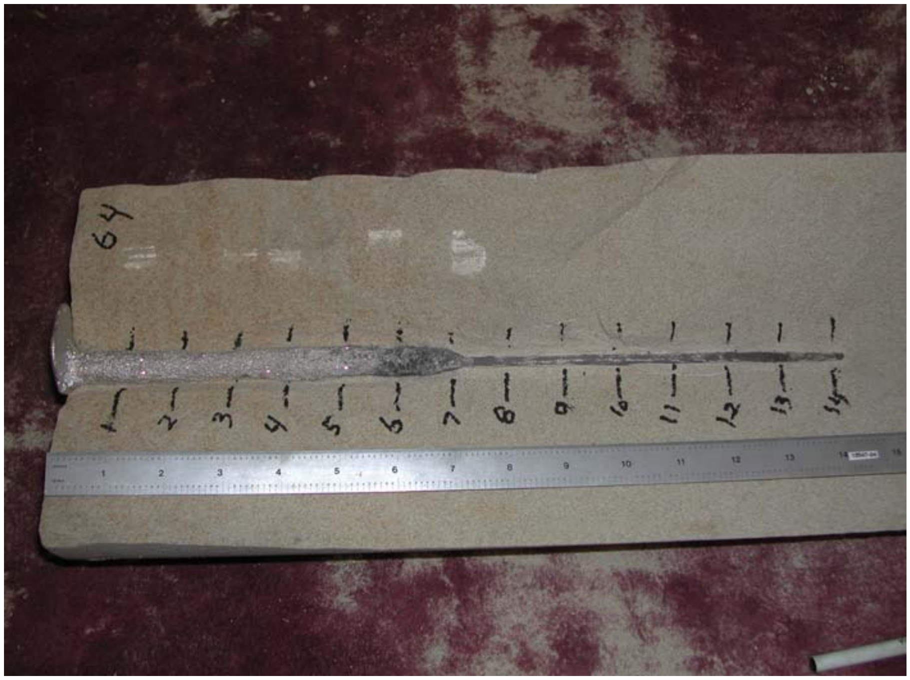

Figure 7a - Core Shot at Balance Condition

Figure 7b - Core Shot at 3500 psig Underbalance.

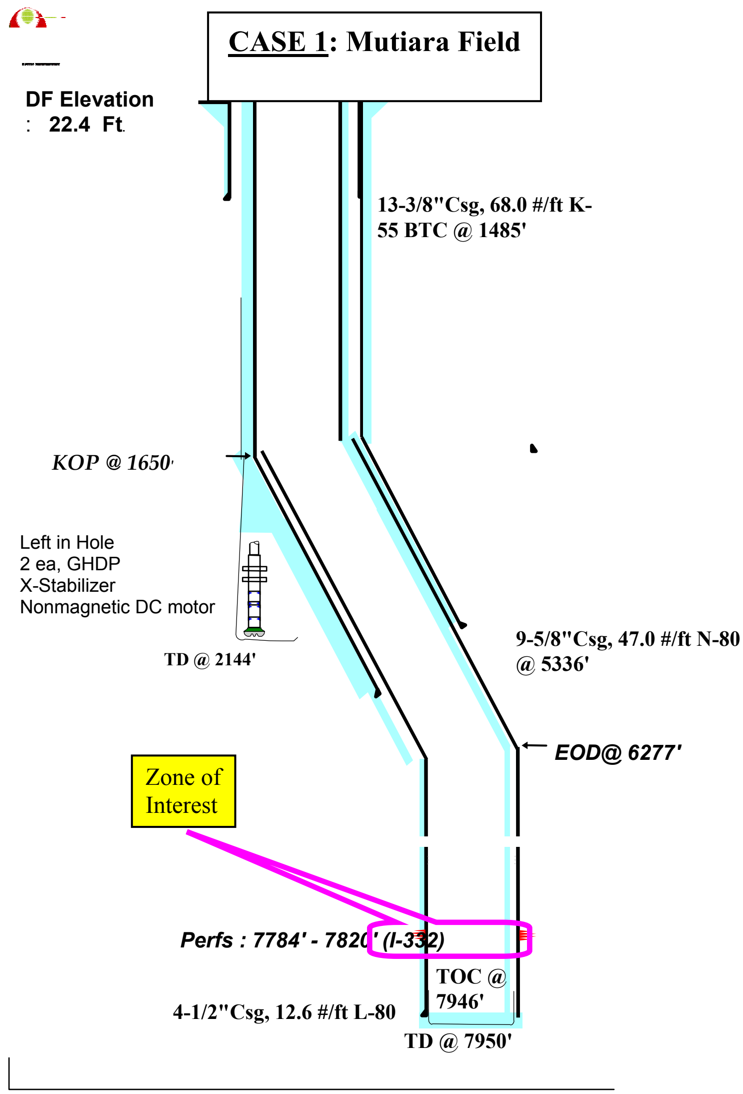

Figure 8 — Wellbore Schematic in the Mutiara Field

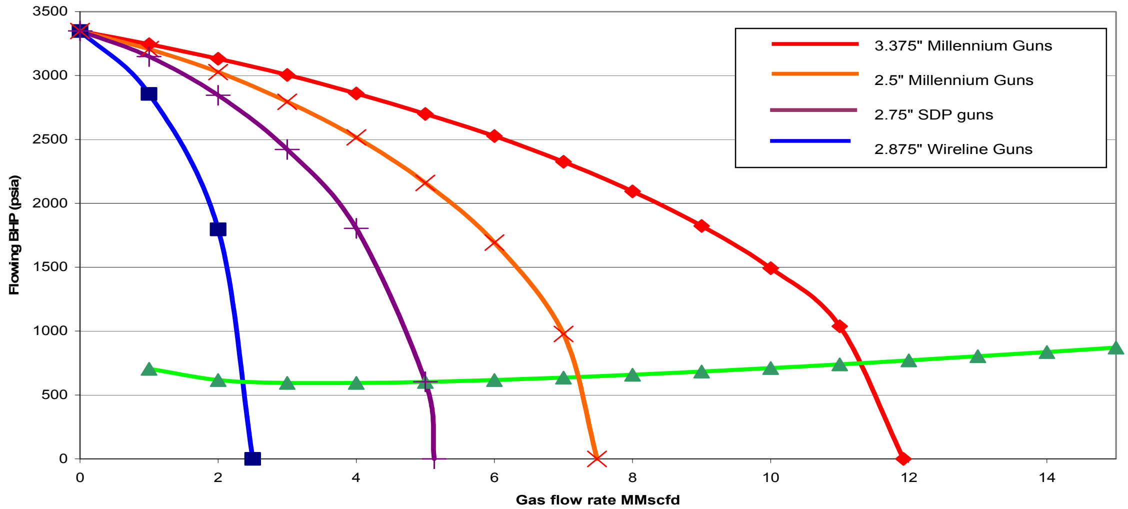

Figure 9 — Inflow Performance Profile in the Mutiara Field Using Different Perforating Techniques and Perforators

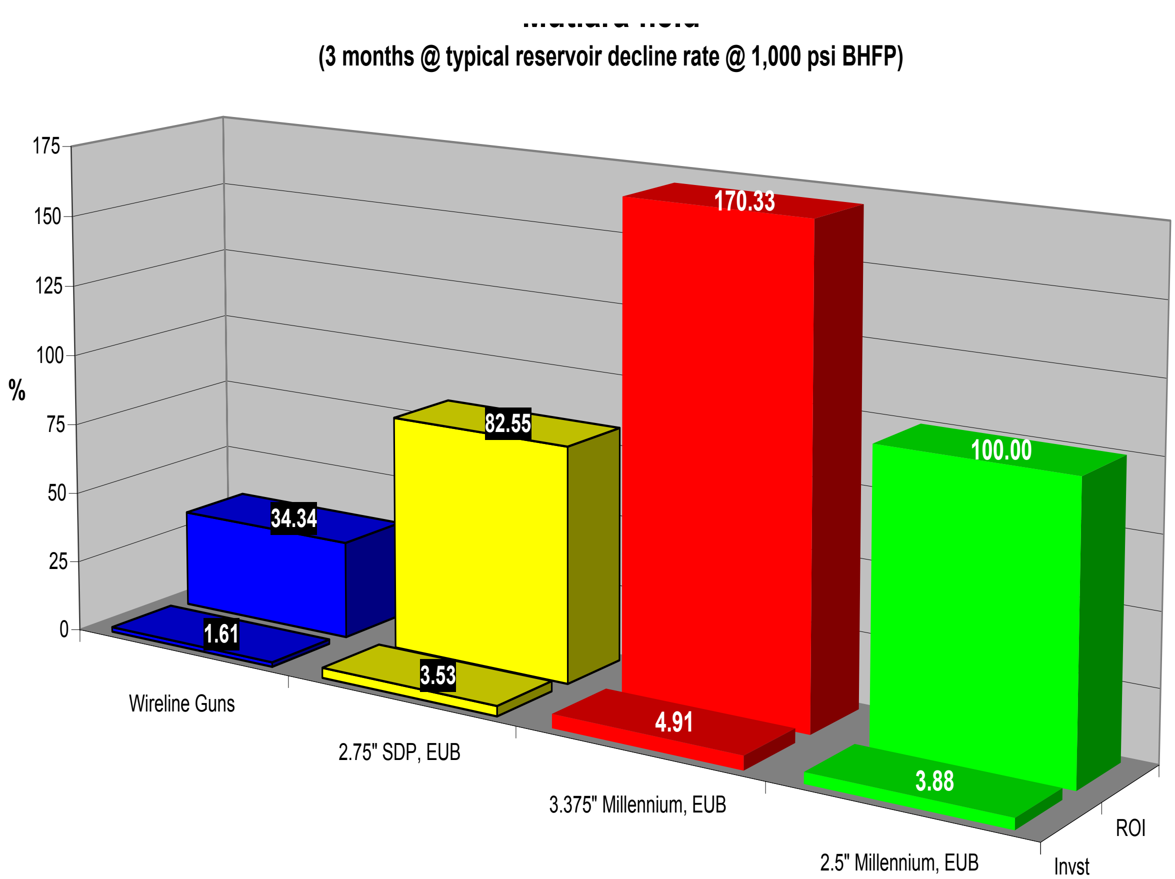

Figure 10 — Economic Evaluation of the Perforating Techniques and Perforators

CASE 2: Nilam Field

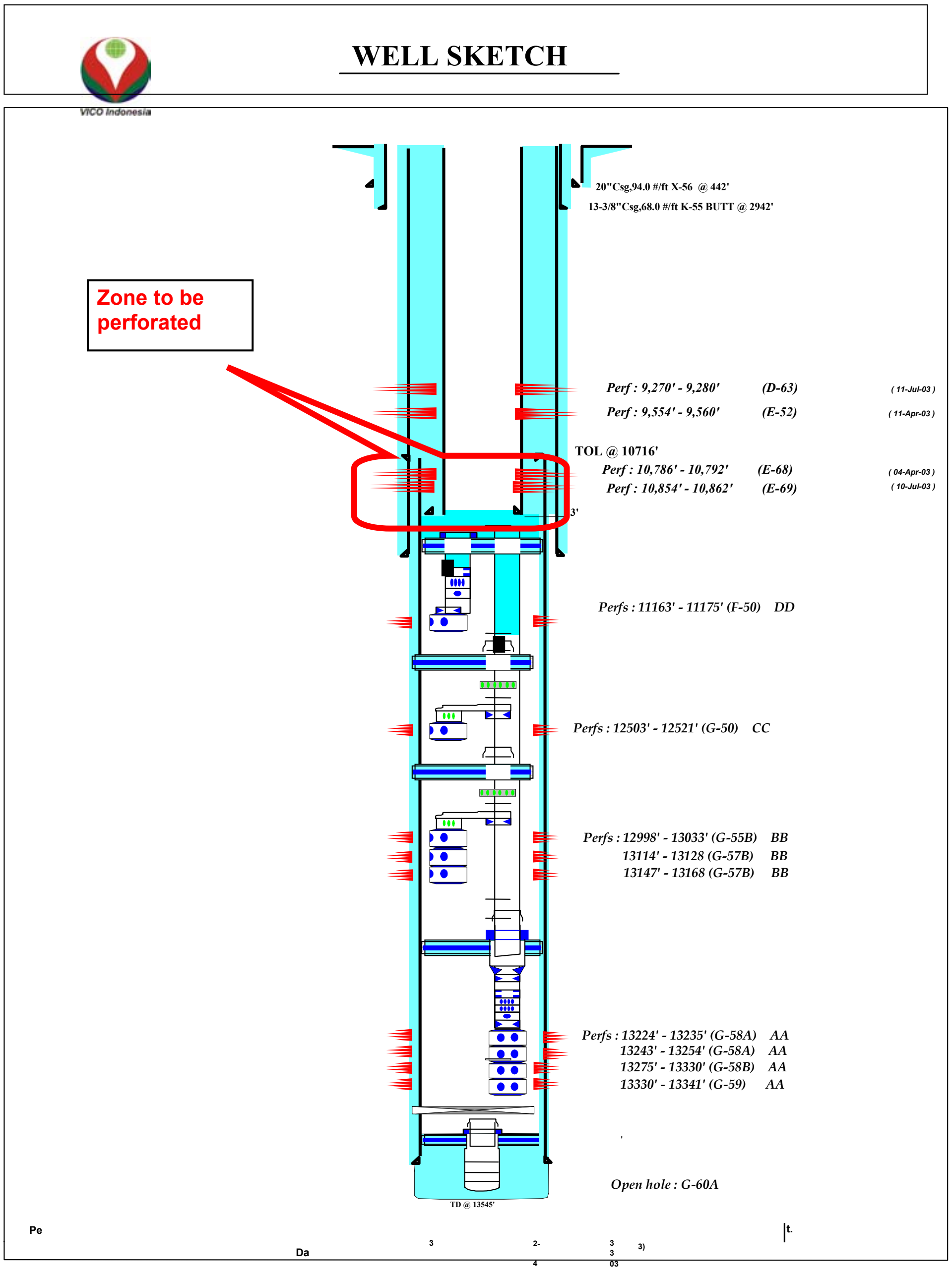

Figure 11 — Wellbore Recompletion in the Nilam Field

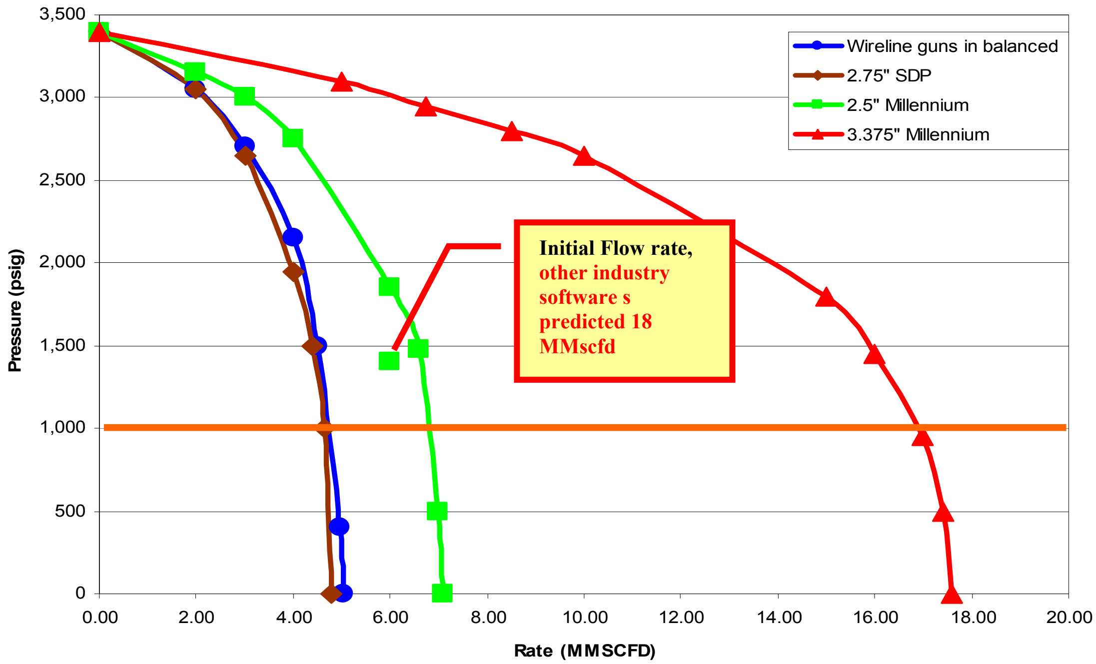

Figure 12 — Inflow Performance Relation of the Zone Using Different Perforating Techniques and Perforators

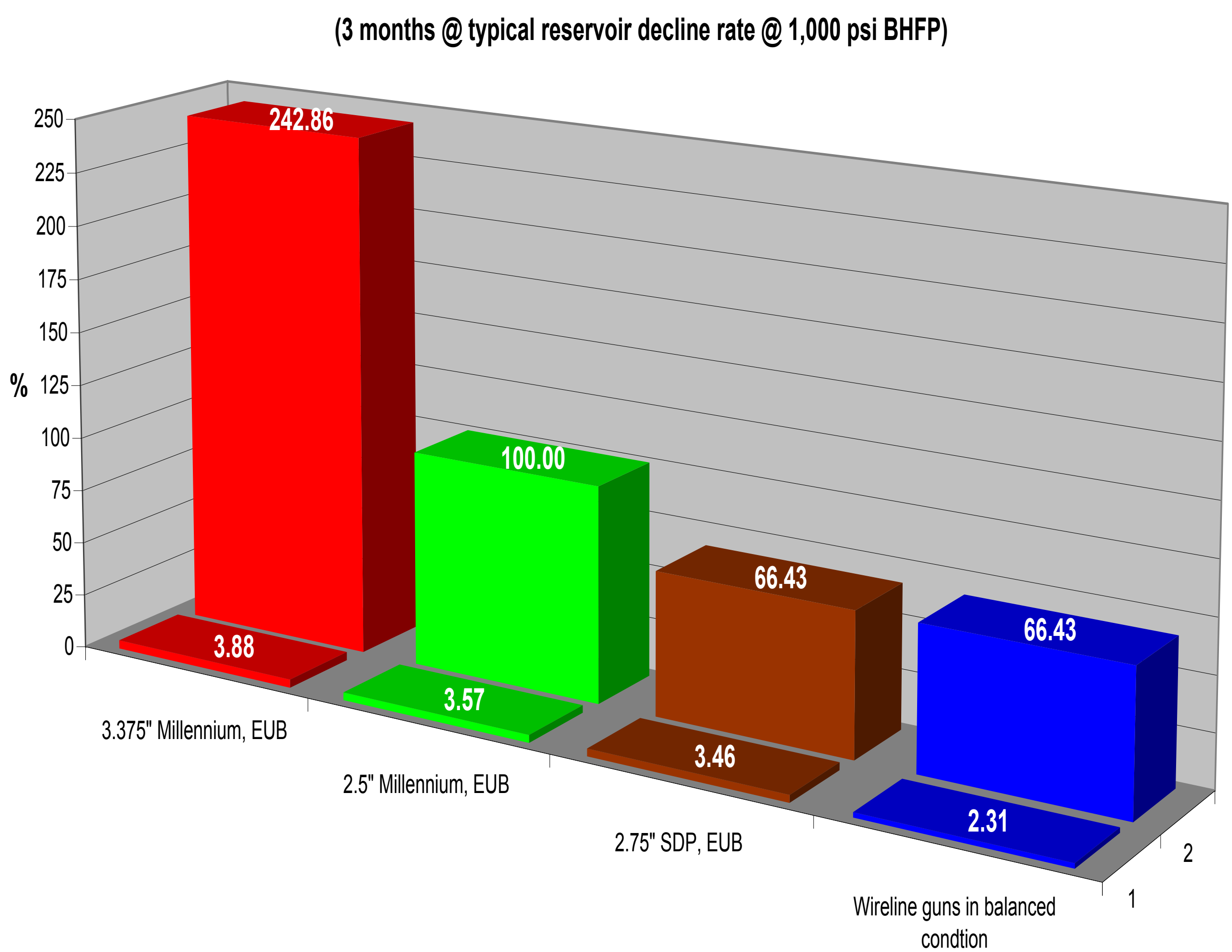

Figure 13 — Economic Evaluation Using Different Perforating Techniques and Perforators

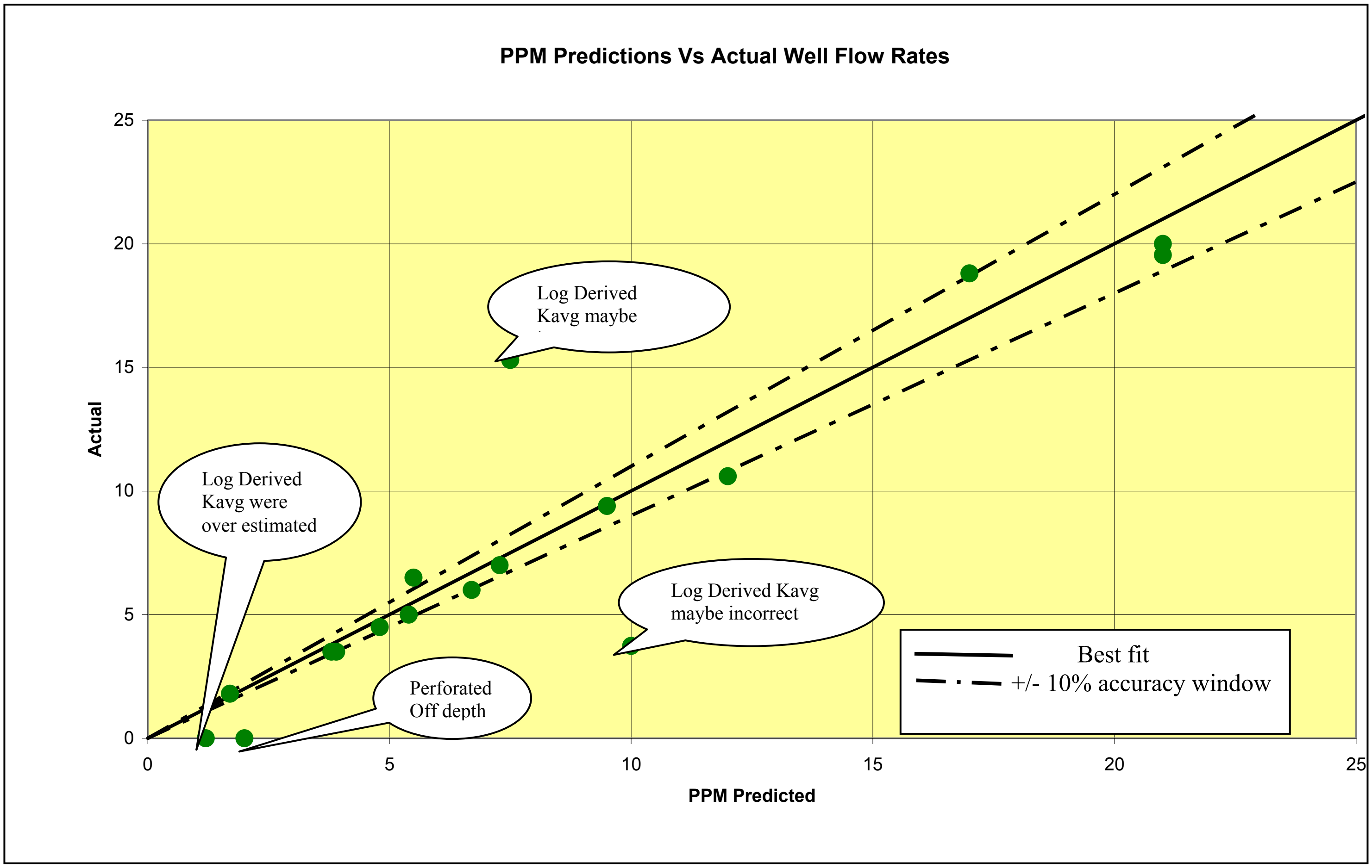

Figure 14 — PPM Pedicted Versus the Actual Well Performance