

CONTRIBUTION OF HORIZONTAL DRILLING TECHNOLOGY IN THE DEVELOPMENT PROGRAMS OF SAUDI OIL FIELDS

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ABSTRACT

The technology of drilling and production of horizontal wells is probably one of the most significant breakthrough in the oil and gas industry of the eighties. The continuous improvement of hardware equipment made horizontal drilling cost-effective technique for developing reserves, improving productivity and recovery in oil and gas reservoir.

This paper is devoted to Saudi experience in horizontal drilling. The last years have been an exciting period for those who believed in horizontal drilling applicability in Saudi Arabia. At the end of the year 1997 over than 150 horizontal wells have been drilled in Saudi oil fields. There are four major horizontal well applications identified in Saudi Arabia oil fields; 1) Control of coning in relatively thin remaining oil column area, 2) Improving sweep efficiency of water flooding program, 3) Improving productivity rate in thin/tight reservoirs and 4) Saving in total development costs in conjunction with previous three applications.

This paper presents the major areas of application of horizontal wells and more specifically the objectives of applying horizontal drilling in different Saudi oil fields and the world horizontal drilling activities along with the Saudi experience will be covered. This paper surveys different field examples to show the application trends of horizontal well technology in both offshore and onshore oil fields. The main objective of this survey is to demonstrate the performance improvement of these oil fields after the application of horizontal well technology.

1. INTRODUCTION

The drilling and production of horizontal well have been recognized as one of the most important technical achievement in the oil and gas industry in the last twenty years. Such technology was considered at the beginning an exotic way of drilling, the economical applicability of which was contemplated with some skepticism by reservoir and production engineers. A major breakthrough in horizontal drilling was made with the introduction of the downhole turbodrill/bent sub combination for direction drilling. Rapid advancement in directional guidance technology such as the development of steering tools, new tools e.g. resistivity at bit (RAB) and non directional tools involved in measurement while drilling (MWD), led to a recent surge in the usage of horizontal drilling within the industry.¹

The industry demand of horizontal drilling technology has produced a variety of new applications and techniques. During the period 1980 to 1984, only one or two horizontal wells were drilled worldwide per year, but in 1988 that number of horizontal had jumped to over 200 wells. Since then a gradual increase in wells has been noticed with 1570 wells being drilled in 1994. Current industry projections are that by the year 2000 over 5000 wells per year will be drilled horizontally. Fig. 1 illustrates horizontal well profile with different horizontal section lengths.¹ Record for Statoil holds long horizontal section in Norway (8758 m). The productivity improvement comparing to that of a vertical well in the same reservoir with the use of horizontal well is controlled by horizontal section length, target layer thickness and permeability heterogeneity.

In Saudi Arabia-Kuwait Neutral zone a 2000 ft horizontal well completed in the upper layers of a 40 years old depleted reservoir would produce seven times more than a vertical well in the same location, over five years period. The potential of horizontal wells has recognized throughout the Middle East but it is in Oman that has seen the most radical changes. By the end of 1994 the number of horizontal wells were more than 200 in Oman, 80 in Saudi Arabia, 50 in Abu Dhabi, 20 in Kuwait and 6 in Egypt.² Such kind of success and continuous demand of horizontal well technology do not come by chance. The main factors contributed to it are; the physical basis of the concept was sane, the required technology was made available and there was a market need.

The use of horizontal drilling technology in Saudi oil fields have been for four targets; 1) Control of coning in relatively thin remaining oil column areas, 2) Improvement of water flooding program efficiency, 3) Improvement of productivity rate in thin/tight reservoirs and 4) Saving in total development costs in conjunction with the previous three points.

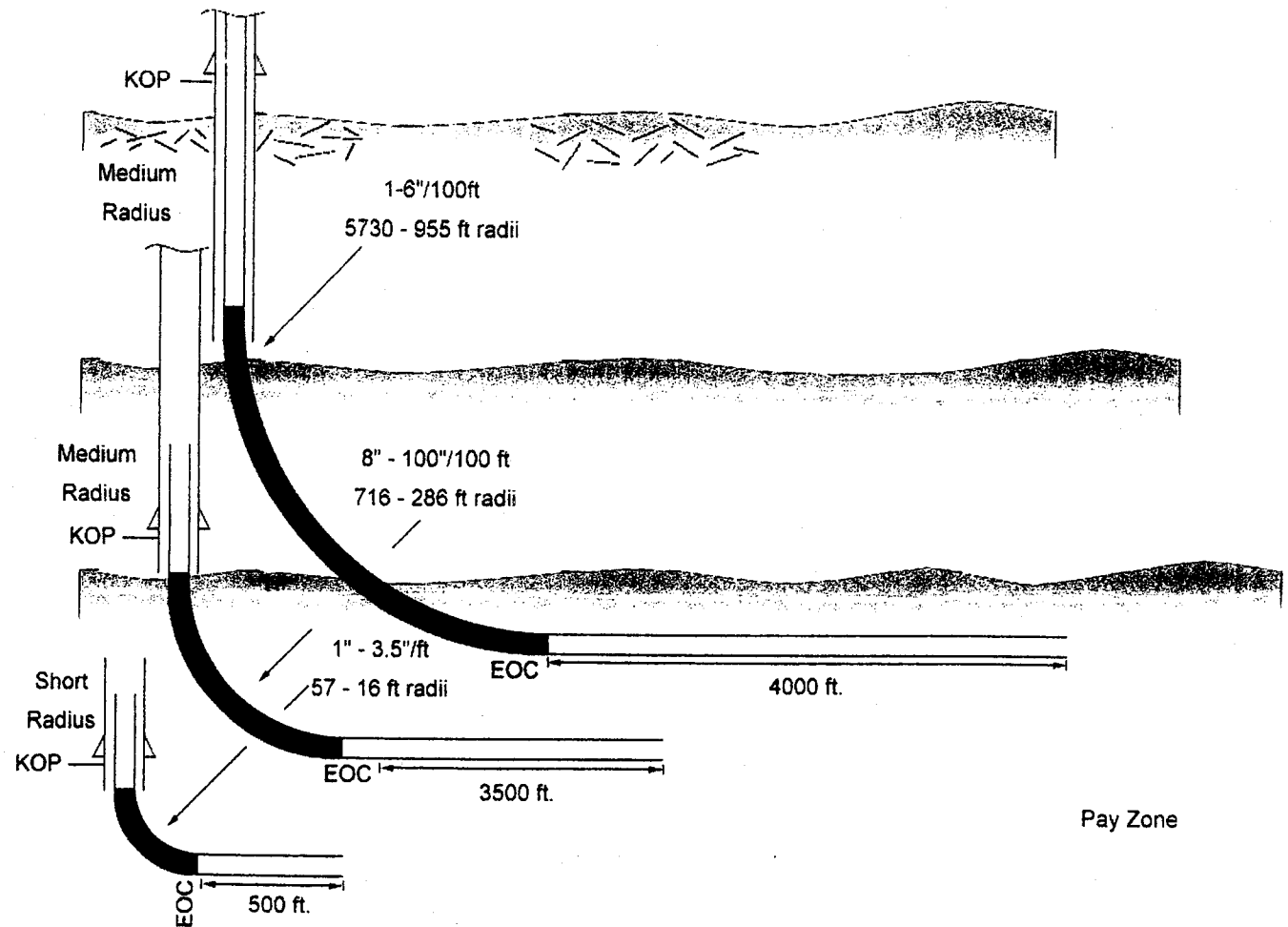


Fig. 1. Three horizontal sections with different lengths and radius of horizontal wel

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The operating companies in Saudi Arabia are committed to apply this technology in a practical and cost effective way by using the emerged technology. This paper reviews the fields of application of horizontal wells and more specifically in the offshore and onshore Saudi oil fields. Also the paper discusses the net benefits gained from the use of horizontal well technology in Saudi oil fields.

2. HORIZONTAL DRILLING APPLICATIONS

Horizontal drilling should be considered for any exploration and development programs. The main goals of horizontal drilling are; maximize the ultimate recovery factor, maximize the economics of recoverable reserves, sustain a high production rate for as long as possible to optimize ultimate recovery and characterize and evaluate the reservoir in exploration. Certainly not all reservoirs need horizontal wells; some reservoirs should be developed using both vertical and horizontal wells. Increased production of horizontal wells can reduce the number of wells required for infill or development and reduce the number of platforms and/or other structures required in development stages.³⁻⁵

Application of Horizontal Drilling to Exploration

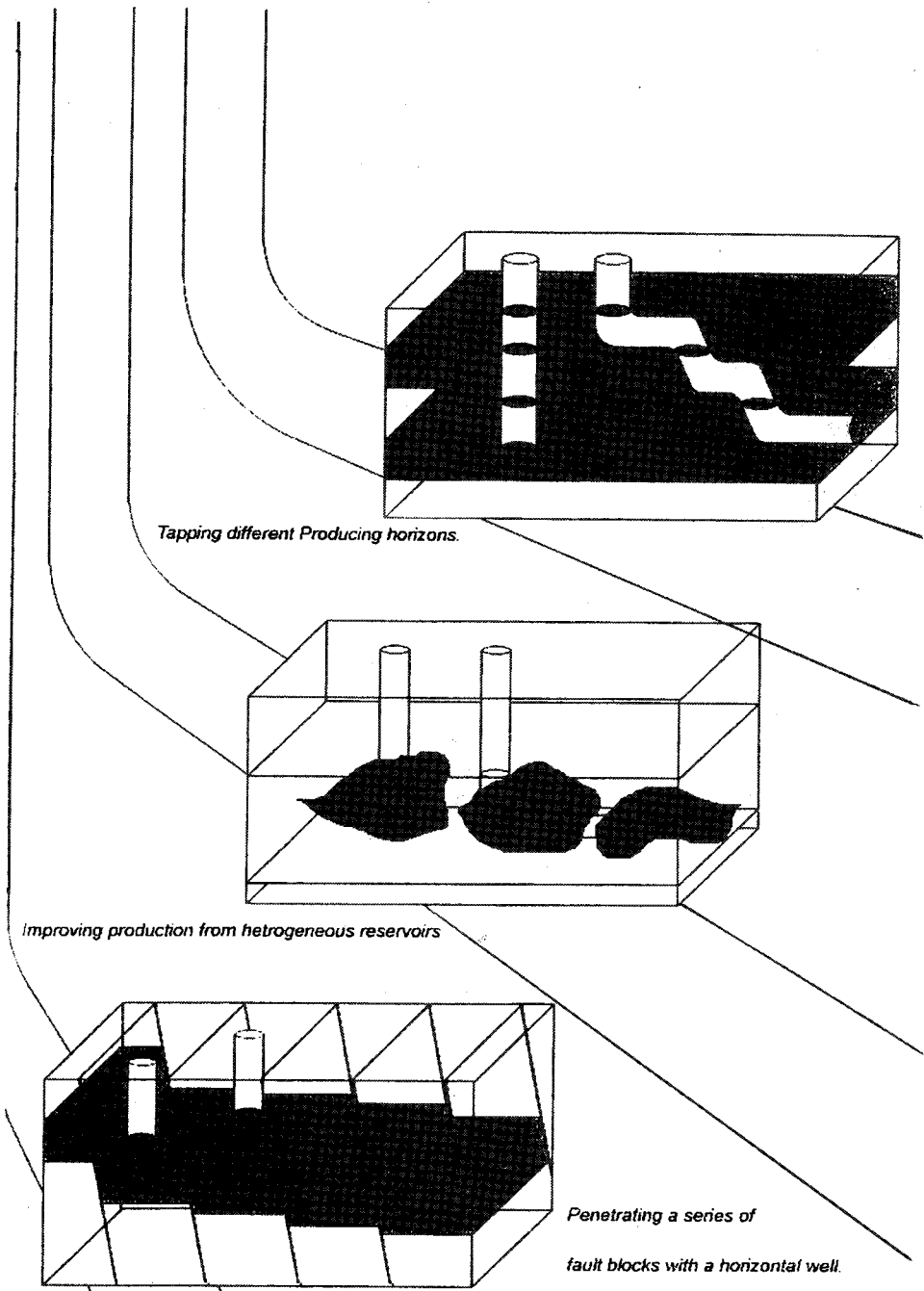
Up to now, horizontal drilling technology has been restricted to production. Exploration could benefit from horizontal drilling, not as primary tool but as a secondary tool. In other words, once the occurrence of the reservoir and structure has been proven by conventional vertical drilling, horizontal drilling can be used to improve the lateral knowledge, and then better definition of reservoir characteristics between vertical wells.

Application of Horizontal Drilling to Reservoir Management

The main objective from reservoir management basis is the best exploitation of petroleum resources in the development and production stages. Horizontal drilling can drastically improve production by greater exposure to a producing zone or zones. A horizontal well may also offer other advantages as decrease of pressure drops and fluid velocities around the wellbore, minimization of water and/or gas coning, and usually acceleration production.

There are several types of reservoirs where production can be increased significantly using horizontal wells: Naturally fractured reservoirs, Thin reservoirs, Heterogeneous reservoirs, Reservoirs under urban areas or offshore, Vertical permeability homogeneous reservoirs, reefs or isolated sand bodies reservoirs and faulted reservoirs. Fig. 2 shows three cases where horizontal drilling was very successful.

Contribution of Horizontal Drilling Technology in the Development.....



Tapping different Producing horizons.

Improving production from heterogeneous reservoirs

Penetrating a series of fault blocks with a horizontal well.

Fig. 2 Three examples of horizontal wells drilling applications. ⁴

Application of Horizontal Drilling to Enhanced Oil Recovery

In active waterflood and enhanced oil recovery (EOR) fields, the use of horizontal wells can provide the following five advantages; 1) An increase lateral sweep efficiency, 2) An increase of drainage and swept volume in severely faulted or heterogeneous reservoirs, 3) A reduction in heavy oil viscosity via efficient steam injection, 4) A reduction in heat loss during steam injection, and 5) A reduction in the number of infill wells required for waterflood or EOR program.

Application of Horizontal Drilling to Drainage Architecture

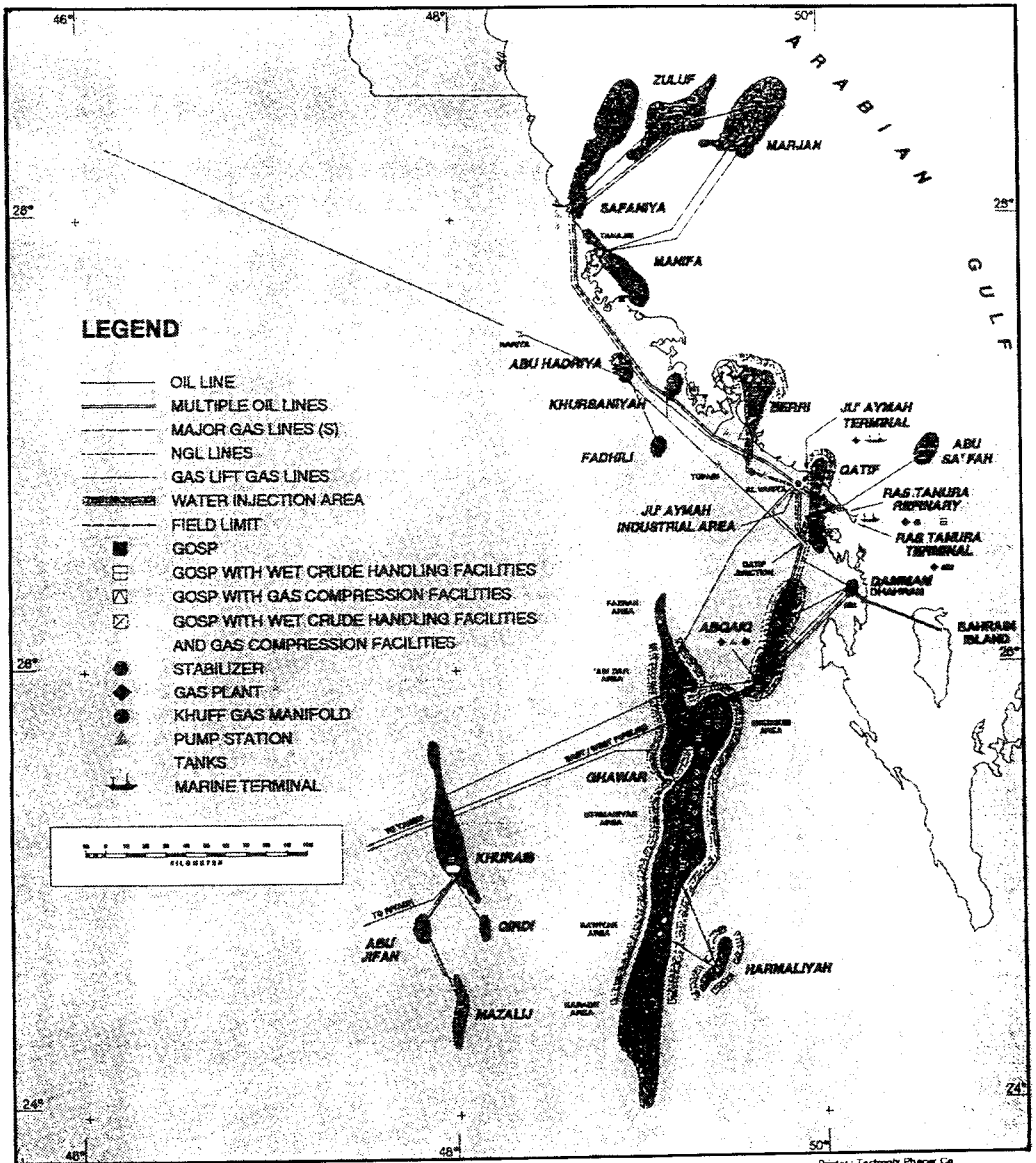
One of the most important openings of horizontal drilling is that it has paved the road to the concept of drainage architecture. Today, it is possible to drill already any type of geometry inside the reservoir and therefore to create any kind of flow pattern. The task of reservoir engineer will be then to define the proper drainage architecture adapted to the fluids, the production mechanism and the characteristics of the formation. The driller will have then to implement it economically.⁶

3. HORIZONTAL DRILLING APPLICATIONS IN SAUDI OIL FIELDS

The producing fields of Saudi Arabia contain the largest concentration of oil reserves in the world. Ghawar is the world's largest onshore field and Safaniya is the world's largest offshore field. In total, more than 50 fields have approximately 250 sandstone and carbonate reservoirs. Fig. 3 shows the distribution of offshore and onshore fields in Saudi Arabia.⁷ Saudi Arabia contains an estimated remaining proven reserve base of over 257 billion stock tank barrels of crude. These reserves represent 25 % of the world proved reserves. This large crude oil reserve has positioned Saudi Arabia to apply horizontal well technology to be able to improve reservoir performance, to cost effectively implement the development projects and to explore for and produce from difficult oil and gas formation settings.

The maturing of specialized drilling techniques has now placed the world in a position to more fully exploit horizontal wells. Fig. 4a illustrates the boom in horizontal drilling activity in the world and North America in the 90's and Fig. 4b shows the rate of growth of horizontal drilling activity in Saudi Arabia. The comparison between (Fig. 4a) and (Fig. 4b) demonstrates that oil companies in Saudi Arabia are making optimum use of the emerging world experience in this new and exciting horizontal well technology. In Saudi Arabia, horizontal wells have been used in offshore fields and onshore fields to solve their arisen problems.⁸⁻¹⁰

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Job done by : Jowell C. de Guzman
 Date : October 03, 1990
 Computer Machine : Macintosh IIfx (300DPI)

Printer : Techronix Phaser Cg
 Color Printer with 300DPI
 SAUDI ARAMCO (Saudi Arabian Oil Company)

Fig. 3 Distribution of offshore and onshore oil fields, Saudi Arabia. ⁸

World and North America

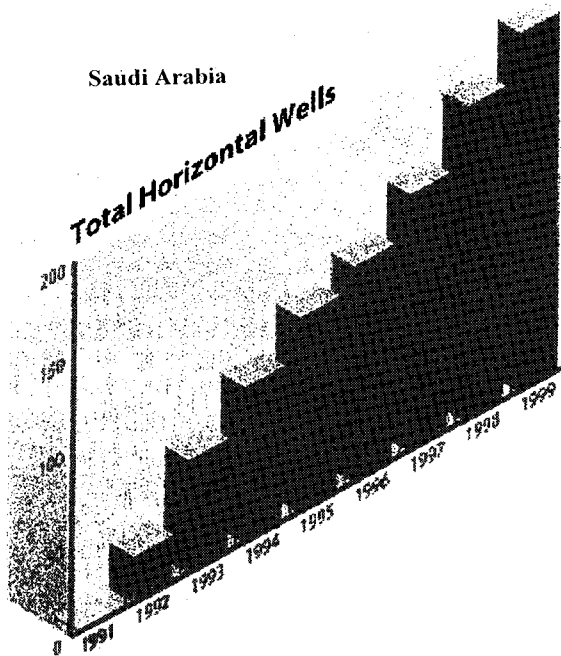
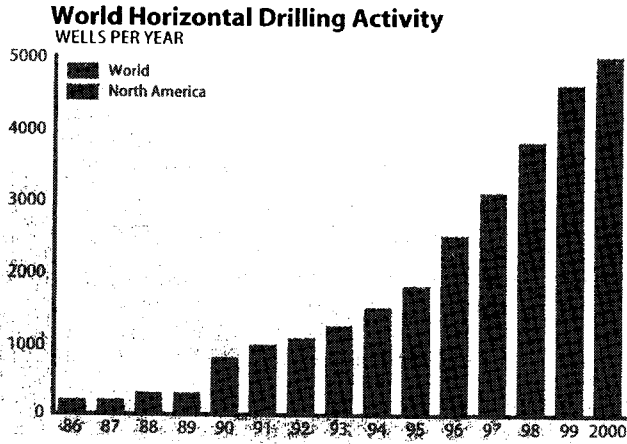


Fig. 4. Number of drilled and planned horizontal wells up to year 2000.¹⁰ Saudi Arabia, World and North America.

OFFSHORE FIELDS

Berri field

Berri field is located both onshore and offshore along the western edge of the Arabian Gulf. Its 1994 daily production rate was about 300,000 STB. Berri field is the first field to have horizontal drilling technology applied. The carbonate nature of the reservoir improves hole stability and makes possible open hole completion hole that give two times conventional well rates. A great advantage of horizontal wells over verticals is an increased exposure to the wellbore of thin oil columns and /or tight rock sections. Fig. 5 shows a horizontal section of more than 1500 ft. was drilled along the top of the reservoir above the OWC and away from the water cone. The well has since produced very little water.

Marjan Field

Marjan field is located 9 miles offshore in the Arabian Gulf. Its 1994 daily production was about 400,000 STB. The field consists of four main areas: Marjan, Lawhah, Maharah and Hamur with 13 oil bearing reservoirs. The Khafji reservoir is the only zone on production. It suffers from a strong water drive and a large gas cap. The objective of 13 horizontal wells drilled in this zone is to reduce coning of gas and water. The target rate of these wells is twice that of the conventional well.

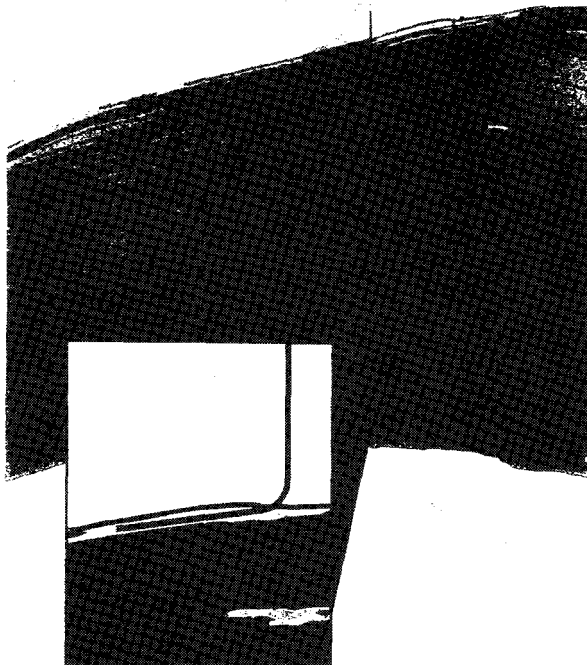


Fig. 5 Horizontal well drilled to produce thin oil layer, Berri field. ¹⁰

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Fig.6 shows the profile of a horizontal well in Khafji zone. Also three horizontal wells have been drilled Khafji thin stringers sands. These wells have shown that horizontal wells can be cost effective way to improve productivity in thin reservoirs.

Zuluf field

Zuluf field is one of the northernmost fields in Saudi Arabia and is located about 35 miles offshore in the Arabian Gulf. Its 1994 daily production was about 500,000 STB. The field contains 8 oil and gas bearing reservoirs. Khafji reservoir is the main reservoir and it has string water drive and a gas cap. Three horizontal wells have been drilled in the Khafji main sand to control gas and water coning. Thus, the productivity has reached four times that of nearby vertical wells. In Khafji stringers, three horizontal wells have been drilled to exploit these thin sands. Fig. 7 shows a horizontal well in Khafji stringers. Production in these wells has been doubled that of the offset vertical wells.

Safaniya field

The Safaniya field is the world's largest offshore oil field. Safaniya field is divided into three areas: North, Central and South. There are 8 producing reservoirs. Its 1994 daily production was about 960,000 STB. The Safaniya and Khafji reservoirs are the main producers. The objective of horizontal drilling in this field is to reduce coning in the areas where there is a thin oil column.

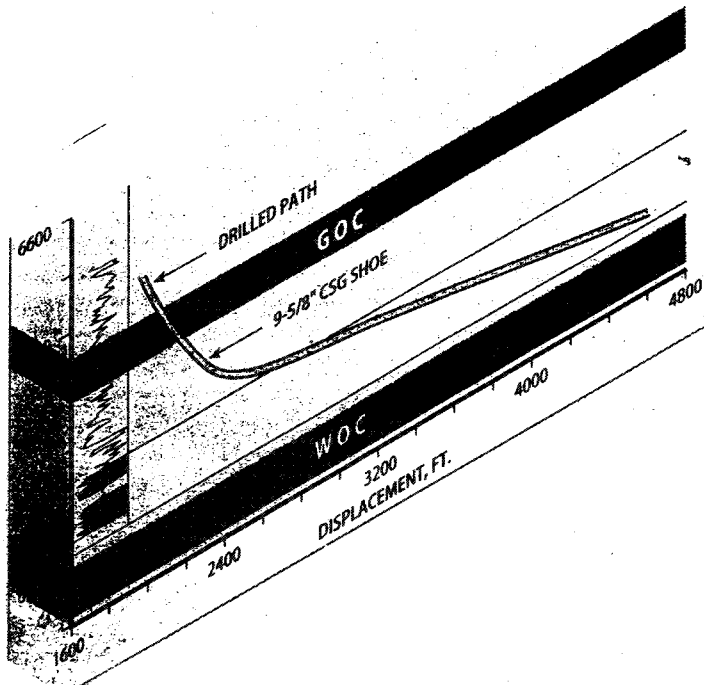


Fig. 6 Horizontal well drilled to overcome water/ gas coning problem, Marjan field.¹⁰

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Khafji Main Sand



Khafji Stringers

Fig. 7 Horizontal well mitigates gas coning in Khafji sand, Zuluf field, ¹⁰

Fig. 8 shows horizontal well profile in Safaniya sand. Six wells have been drilled in Safaniya fields, two in Khafji reservoir and four in Safaniya reservoir. All wells were drilled to reduce water coning and adverse mobility ratio. These wells have outperformed the conventional wells by a factor of two.

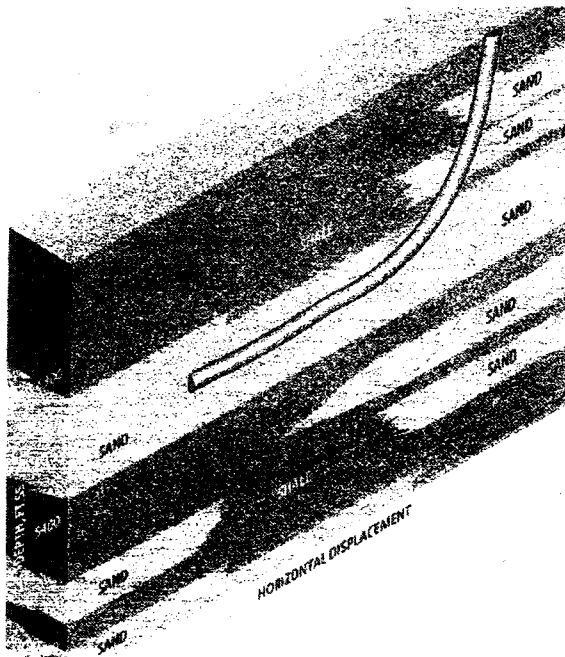


Fig. 8 Horizontal drilled to reduce water coning in Khafji sand, Safaniya field. ¹⁰

Onshore Fields

Ghawar field

Ghawar field is the largest producing field in the world. Its 1994 daily production was about 5,000,000 STB. The Ghawar contains several producing reservoirs. All reservoirs are carbonates, the main producing formation is the Arab-D sequence. Significant number of horizontal wells were targeted in Ghawar field to increase the efficiency of the waterflooding program, by improving sweep efficiency and injection performance, and to capture additional oil. Application of horizontal drilling to producers has just begun in Ghawar. Fig. 9 shows a model of a horizontal well at the top of Arab-D sand reservoir in area of thin oil column to increase the efficiency of the water flooding program and produce all available oil. This injection program has enabled the wells in Ghawar to continue to flow under their own pressure.

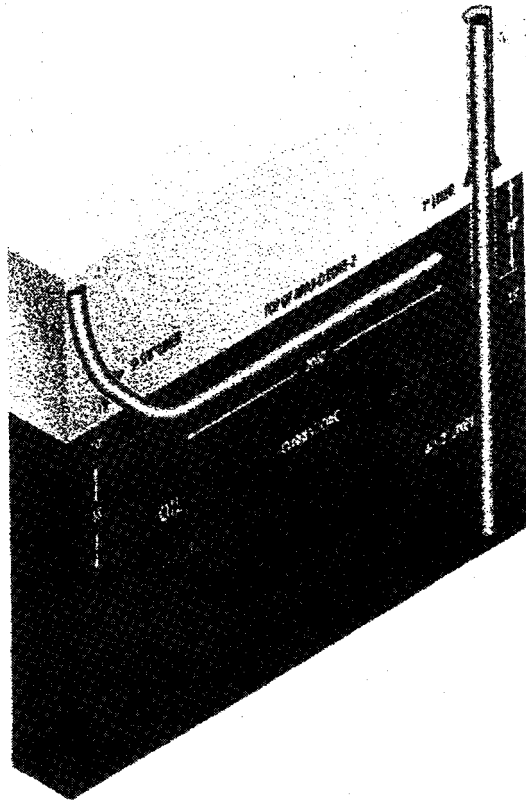


Fig. 9 Horizontal well drilled at the top of Arab-D to increase the efficiency of water flood Program, Ghawar field. ¹⁰

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Abqaiq field

Abqaiq is one of the maturest oil field in Saudi Arabia. This onshore field was discovered in 1940 and production begun in 1946. Its 1994 daily production was about 650,000 STB. Abqaiq contains four producing bearing sequences. Horizontal well were drilled in Arab-D formation in area of thin oil column to increase the efficiency of the water flood and capture all available oil. Vertical wells in such areas have high water cuts and are produced at restricted rate to avoid water coning. Horizontal wells have higher rates. Fig. 10 shows a horizontal well traversing different producing layers of Hanifa reservoir in Abqaiq field.

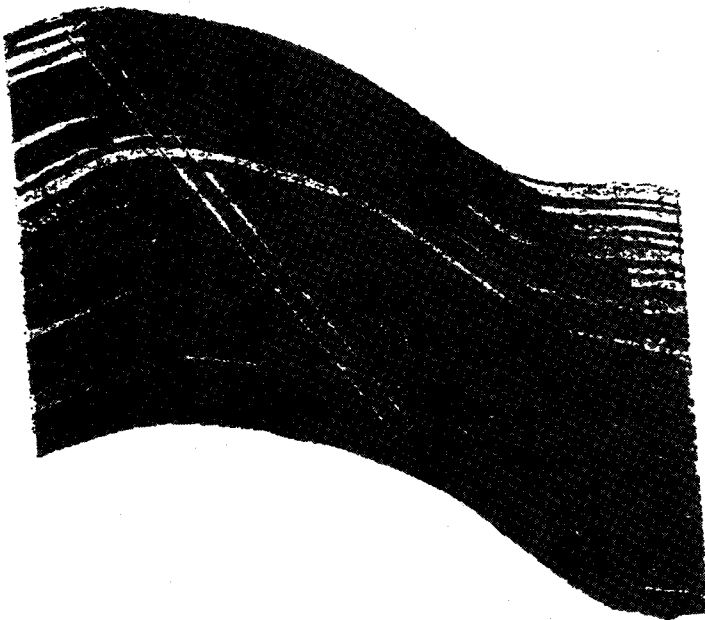


Fig. 10. Horizontal well dilled to traverse multi- producing layers of Hanifa reservoir, Abqaiq field. ¹⁰

4. ECONOMICS OF HORIZONTAL DRILLING IN SAUDI ARABIA

By the end of 1994 over than 80 horizontal wells have drilled in Saudi Arabia at a total cost of more than 350,000,000 \$. Fig. 11 illustrates the distribution of these wells according to type of the field offshore or onshore, nature of the drilled well as producer or injector, lithofacies nature of producing zones (sandstone or carbonate) and according to the reasons for horizontal well drilling decision. The application of horizontal drilling

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program in Saudi oil fields has yielded several benefits; 1- Improves well capacity by 150- 400 %, 2- Reduces total number of wells by 30 %, 3- Reduces water/gas handling costs by up to 50%, 3- Reduces total drilling, flowline, facilities cost by 20-25% and 4- Control well and reservoir technical performance problems.

Operating companies specially Saudi Aramco are committed to use horizontal well technology as well cost effective as reservoir performance enhancement technology. Fig. 12 illustrates very well this economic commitment. Relative cost curve of a horizontal well to a vertical well is approximately close to one in offshore and offshore fields in the period 1992-1994.

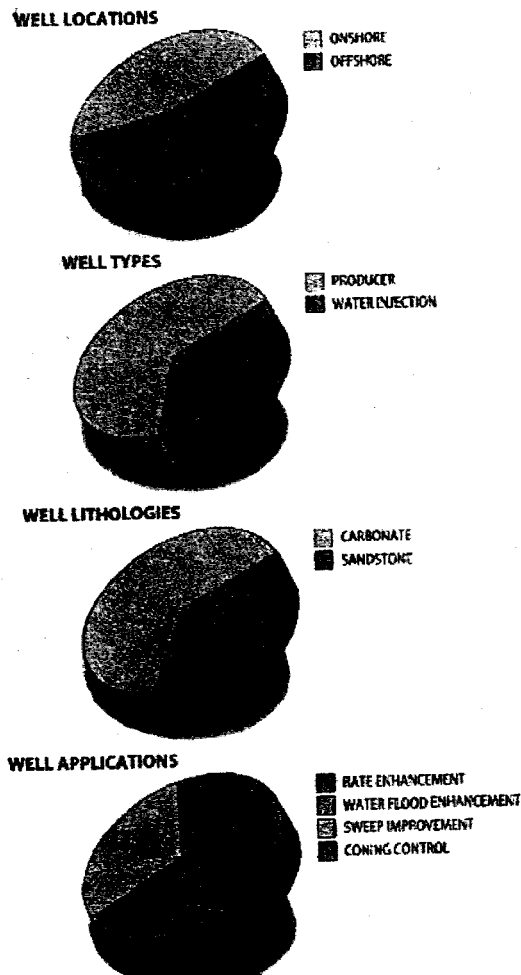


Fig. 11 Distribution of horizontal wells drilled in the Saudi oil fields. ¹⁰

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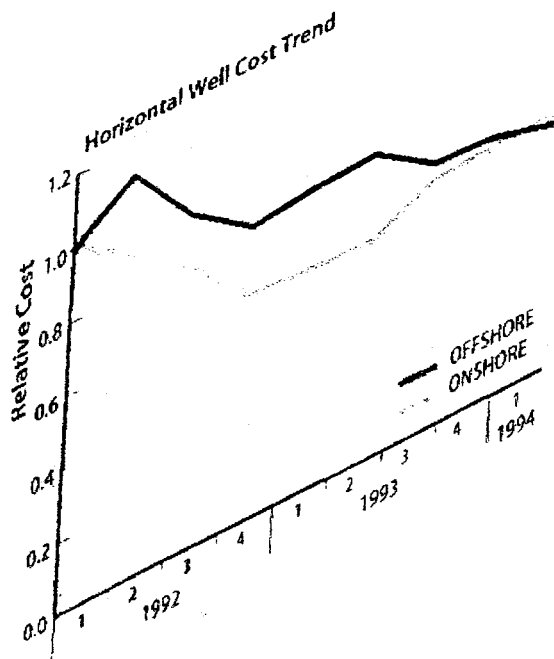


Fig. 12 Horizontal / vertical well relative cost in offshore and onshore fields. ¹⁰

5. CONCLUSIONS

1. Horizontal drilling technology is the most effectively expanding technology in the last ten years to improve productivity, control adverse and damaging reservoir conditions and enhance recovery of oil and gas reservoir and also to explore and produce oil and gas under difficult geographical and geological settings
2. Application of horizontal well technology in Saudi Arabia has accomplished the planned targets:
 - Control water and gas coning problems in offshore and onshore fields
 - Improve the efficiency of waterflooding programs
 - Increase productivity of tight reservoirs
 - Increase productivity of thin oil columns reservoirs
 - Improve capacity of producing wells
 - Reduce the total number of infill and development wells.
 - Reduce total drilling, flowline, facilities and water/gas handling costs.

REFERENCES

1. **Giannesini, J.F., 1992.**, "Horizontal Wells: An Overview" OAPEC-IFP Workshop on Horizontal Drilling and Application, Paris.
2. **Petit, H. and Lesage, G. 1992**, "Adapted Screening Procedure, Key to Successful Horizontal Well Engineering Projects" OAPEC-IFP Workshop on Horizontal Drilling and Application, Paris.
3. **Schlumbergure Oil Services, 1991**, "Horizontal Well Technology" Horizontal Well Technology Seminar, Cairo.
4. **Hamada, G.M., 1996**, "Horizontal well Technology in Egypt" EGPC Seminar on Horizontal Well Technology, Cairo.
5. **Hamada, G.M. and Al-Blehed, M.S. 1999**, "Emerged horizontal drilling technology and it's applications in Saudi Oil fields in the last ten years" SPE# 57322 Presented at Asia Pacific Oil and Gas Conference, Kuala Lumpur, Malaysia.
6. **Renard, G. and Sabathier, J.C., 1992**, "Integration of Horizontal Drilling into Reservoir Management Practice" OAPEC-IFP Workshop on Horizontal Well Drilling and Application, Paris.
7. **Legros, E. 1983**, "A Technical Success for Elf Aquitaine: Horizontal Drilling" Intl.Petrol. Gaz, Chim, pp. 56-59.
8. **El-Malik, M. 1998**, "Notes on Petroleum Engineering", King Saud University,
9. **Al Burak, K.A. 1992**, "Application of long radius horizontal drilling technology in Saudi Arabia: a case history": OAPEC _IFP Workshop on horizontal well drilling and application, Paris.
10. **Ogawa, N. and Minh,C.C. 1977**, "Log interpretation and partial solutions in horizontal wells drilled offshore-Neutral Zone" SPE# 37775 Presented at the 10th MEOS, Bahrain, 15-18.
11. **Saudi Aramco, 1995**, "Horizontal Drilling in Saudi Arabia" Saudi Aramco Pub. Summer,