HORIZONTAL AND MULTILATERAL WELL TECHNOLOGY

Sada Joshi
Joshi Technologies International, Inc., Tulsa, Oklahoma, USA

Keywords: Horizontal well, multilateral well, slant well, fracturing, gas coning, water coning, water flooding, mud motors, angle build motor, casing, porosity, permeability, permeability ratio, turn radius, ultra short radius, short radius, knuckle joint, downhole, total vertical depth (TVD), well tolerance, stand-off, kick-off, formation damage, coiled tubing, artificial lift or pump, pressure drawdown.

Contents

Summary

Since 1980, progressively more and more horizontal wells and multilateral wells are being used for the development and production of oil and gas fields around the globe. This chapter includes a summary of horizontal and multilateral well technology as of 2007.

The chapter also describes various oil fields where horizontal and multilateral wells are used. A horizontal well is one that is typically drilled parallel to the bedding plane of an oil or gas bearing reservoir. Drilling 2000 to 3000 ft (600 to 900 m) long wells has become quite common.

The main reasons for drilling horizontal wells are: 1) their stabilized production rate is about 2 to 5 times more than that of vertical wells, 2) depending upon the location and type of drilling technique used, the cost of a horizontal well is 0.6 to 2 times the cost of conventional wells, and 3) the cumulative oil and/or gas produced by a horizontal well is about 2 to 6 times more than that of a conventional vertical well.

In short, horizontal wells generally provide better economics than conventional wells.

This chapter includes descriptions of: 1) types of horizontal wells and the techniques used to drill them, 2) how to complete and produce horizontal wells, 3) mathematical equations to estimate production rates from horizontal and multilateral wells, and 4) various parameters that influence productivity of horizontal wells. Additionally, the chapter includes several field histories of horizontal and multilateral applications.

1. Introduction

A horizontal well is drilled parallel to the reservoir bedding plane, whereas a vertical well intersects the reservoir bedding plane at 90 degrees. A slant well would be one that intersects the reservoir at an angle (see Figure 1).

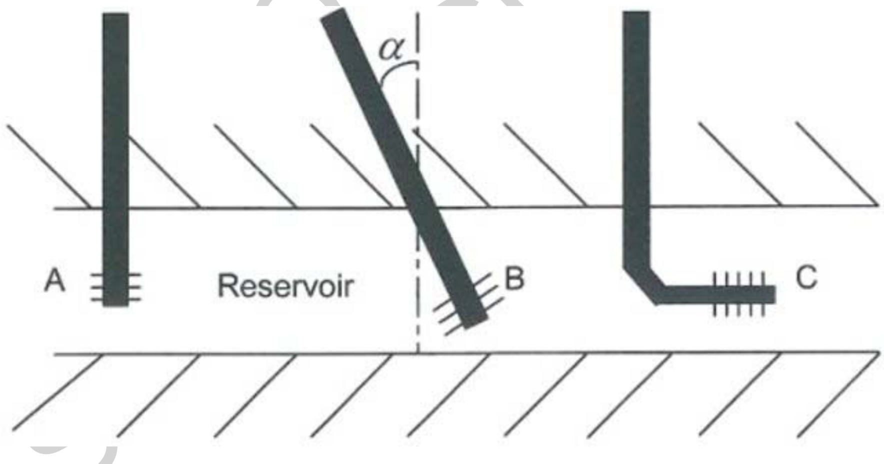

Figure 1. A) Schematic of a vertical well, B) Schematic of a slant well with angle α , C) Schematic of a horizontal well

Multilateral well drilling involves the drilling of two or more horizontal production holes from a single surface location (see Figure 2).

The normal objective of both horizontal and multilateral wells is to produce more oil or gas from a well and to reduce the overall cost of producing each barrel of oil or each cubic foot of gas.

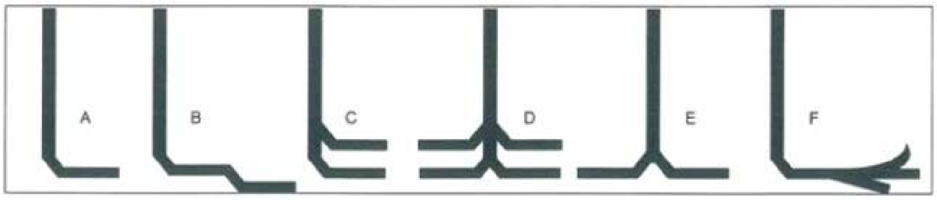

Figure 2. Multilateral Well Configurations

Generally, the productivity of a horizontal well is two to five times more than the productivity of a vertical well. This productivity improvement occurs because of the contact area between the reservoir and the well. Oil and gas reservoirs generally vary in thickness from 20 ft to 300 ft (6 to 90 m). Thus, with a conventional vertical well, the contact area between the well and the reservoir is 20 ft to 300 ft (6 to 90 m), depending upon the reservoir thickness. In a horizontal well, a typical well length is 2000 ft to 3000 ft (600 to 900 m) long, resulting in a very long contact area between the well and the reservoir. Hence, a horizontal well provides 10 to 200 times more contact area with the reservoir than the contact area provided by a vertical well. This large contact area results in higher well productivity for horizontal wells as compared to vertical wells.

Although the common length of a horizontal well is 2000 ft to 3000 ft (600 to 900 m), horizontal wells as long as 8 km have been drilled. Such long wells provide a very long producing length and high well productivity. How far one can drill depends upon the mechanical capacity of the drilling rig. The torque, drag, and weight of the drilling pipe and the casing weight that can be handled by the rig determine how long one can drill. Additionally, the reservoir thickness will also determine how long one can drill. In thin zones, it is difficult to stay in the zone for a very long length. On the other hand, if the reservoir is thick, it may be easier to drill long wells without wandering out of the zone while drilling. Figure 3 shows a typical horizontal well. As seen here, there are four producing layers and the well intersects more than one layer and is not “exactly” horizontal. Thus, this variation in the well depth or elevation while drilling horizontally needs to be taken into account in determining the appropriate depth at which to drill a horizontal well.

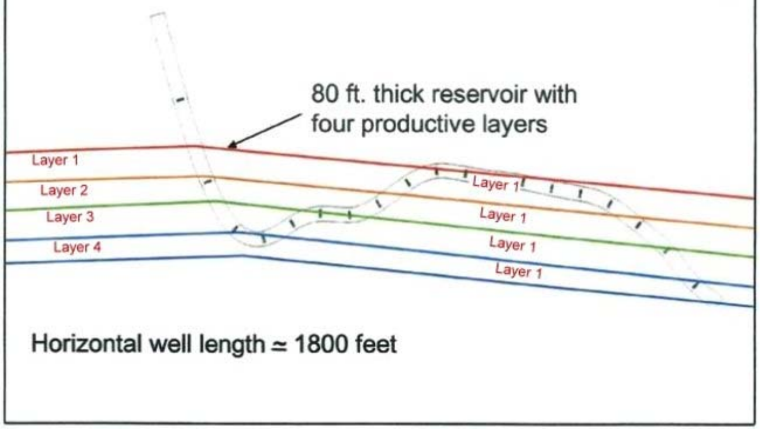

Figure 3. A Typical Horizontal Well Diagram

In cases where rig size is limited, but one wants to drill a long well with a large contact area, multilateral wells provide an option. As shown in Figure 2, one can drill two diametrically opposite wells or other shapes to achieve a large contact area with the reservoir.

The application of horizontal drilling technology in the development of oil and gas reservoirs has become common worldwide over the last quarter of a century. Since 1980, over 50 000 horizontal wells and 1000 multilateral wells have been drilled around the globe. In the United States alone, over 30 000 horizontal wells have been drilled.

Horizontal wells have been drilled in almost all the producing basins in the world. Most of the wells in the (US) United States are in Texas, and mostly in the Austin Chalk or the Barnett Shale formations. In contrast, outside the US, many wells drilled around the globe are in sandstone formations and many are drilled to reduce gas and water coning.

Generally, oil and gas wells are typically drilled in carbonate or in sandstone rocks, which exhibit porosity and connectivity of the porous zone to produce oil and gas. These sandstone and carbonate rocks are referred to as reservoir rocks. In a few cases, such as in Indonesia and Japan, oil is also produced in volcanic rocks.

Generally, shale (sandstone with a very fine grain size) is a source rock, where oil generates and then migrates to the reservoir rock. Shale generally exhibits very high porosity, but lacks connectivity between the porous zones.

In the US, thousands of horizontal wells have been drilled in source rocks such as Bakken shale in North Dakota, Barnett shale in Texas and Fayetteville shale in Oklahoma and Arkansas.

A long horizontal well provides connectivity to non-connected porous zones in a shale reservoir facilitating oil and gas production. With a conventional vertical well, one may miss the porous area of the source rock, and the well does not provide connectivity to other porous areas, resulting in a possible uneconomic well. Thus, horizontal wells have been instrumental in producing oil and gas from source rocks.

Another application of horizontal wells in non-conventional reservoirs is in coal-bed methane reservoirs. In coal-bed methane reservoirs, one has to produce large amounts of water from a coal bed to de-water the coal bed.

Gas production can only begin once the target coal bed is de-watered. Generally, the coal beds are thin, 5 ft to 30 ft (1.5 to 9 m) in thickness.

In a few cases even thinner than 5 ft thick coal seams are produced! A horizontal well provides an option not only to quickly de-water the coal bed, but also to enhance gas production from the coal-bed reservoirs.

Hundreds of horizontal wells have been drilled in coal-bed reservoirs in northeastern Oklahoma, in the US, to produce natural gas.

1.1. Field Development Plans

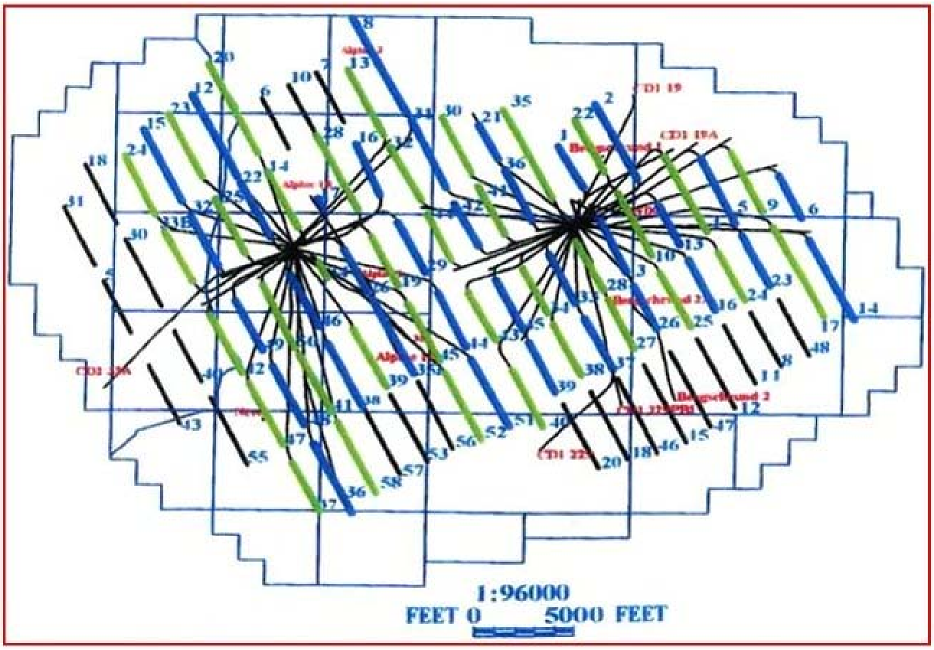

Figure 4. A Typical Field Development Plan – Alpine field, Alaska, USA
Source: "Predicting Success of Horizontal Openhole Completions on the North Slope," Journal of Petroleum Technology, November 2006, p. 48.

A typical field development plan using horizontal wells is shown in Figure 4. It is evident that to develop the field with vertical wells would require many surface locations. On the other hand, by using pad-type drilling, several horizontal wells can be drilled from two surface locations and drain a reservoir which is a few square miles in the areal extent. Such a technique to develop reservoirs has been used in Alaska (USA), Canada, Venezuela, the Middle East, and also in many offshore fields around the world. Such field development, minimizing surface locations, is also possible with multilateral wells.

Minimizing surface locations results in a smaller environmental footprint on the surface, reduces the number of wells required to develop a reservoir, and reduces surface facilities and flow lines required to gather and process the crude oil and natural gas. This results in an overall improvement in the field economics.

1.2. Application

Table 1 shows the various applications of horizontal wells and examples of the sample reservoirs for each application. The table also includes properties of the reservoirs in which the wells have been drilled. As seen from the table, the horizontal wells have been drilled in thin zones, naturally fractured reservoirs, formations with gas and water coning problems, heavy oil reservoirs and in gas reservoirs. Additionally, horizontal wells are now used in water flooding applications along with Enhanced Oil Recovery (EOR) applications such as CO_2 flood and thermal oil recovery.

Reservoir Application	Reservoir	Payzone Thickness	Porosity	Horizontal Permeability
Thin Reservoir	Bakken Shale, ND, USA	10 to 30 ft	1.5 to 12.9 %	< 1 md
Naturally Fractured Reservoirs	Austin Chalk, Texas, USA	25 to 70 ft	3 to 12 %	< 1 md
	Bakken Shale, ND, USA	10 to 30 ft	1.5 to 12.9 %	< 1 md
	Mancos Shale, NM	60 ft (max)	2%	< 0.1 md
	Niobrara, Wyoming, USA		< 10%	< 0.1 md
Formation with Gas & Water Coning	Prudhoe Bay, Alaska, USA (SS)	100 to 200 ft	22%	200 md
	Elk Hills, California (SS)	1500 ft (Orig.) 275 ft (Current)	23%	8 to 80 md
	Bima Field, Indonesia (LS)	20 to 100 ft	31 to 36%	100 to 1000 md
	Gunung Kembang, Indonesia (LS)	35 ft	24%	230 md
	Helder Field, North Sea (SS)	80 to 130 ft		1 to 6 Darcies
	Rospo Mare Fields, Italy (LS)	130 ft	1.80%	2 to 1500 md
	Empire Abo Unit, NM, USA (Reef)	90 ft	8.60%	25 md
	Troll Field, North Sea (SS)	75 ft	30%	6 to 10 Darcies
	S. Pepper Field, Australia (SS)	25 to 75 ft	20%	1 Darcy
	Loma de la Lata, Argentina (SS)	115 ft	14%	1 md
	Chihuido de la Sierra Negra, Argentina (SS)	75 ft	19 to 21%	86 to 164 md
	Nimr Area, S. Oman (SS)	275 ft		
	Safah Field, Oman (SS)		19 to 23%	5 md
	Saih Ruwi Field, Oman (SS)	82 ft	21 to 27 %	1 to 12 md
	Hayat & Salam Fields, Egypt (SS)	30 to 80 ft	14 to 20 %	1000 to 3000 md
Heavy Oil	Countless Upper Manville "RR", Canada		18 to 24%	250 to 5200 md
	Cactus Lake North McLaren, Canada	40 ft	30 to 33%	> 5 Darcies
	Winter Field, Canada	100 ft	30%	6 Darcies
	Edam West, Sparky Sandstone, Canada	65 to 100 ft	34%	1 to 10 Darcies
	Midway Sunset Field, U.S. California	400 ft	28%	1 to 6 Darcies
	Lake Maracaibo, Venezuela	20 ft	17%	440 md
	Jobo Field, Venezuela	100 ft	27%	1700 md
	Cerro Negro Sector, Orinoco Belt, Venezuela		34%	12 Darcies
Gas Reservoirs	Devonian (L. Huron Shale), U.S.	15 to 50 ft	2%	0.13 to 0.43 md
	Big Sandy Field Devonian (L. Huron Shale), U.S.	250 ft (Gross)	2%	0.045 md
	Gulf Coast, U.S. (SS)	40 ft	33%	6 Darcies
	Zuidwal Field, Netherlands	140 to 200 ft	10 to 15 %	1 to 10 md
Waterflood	Weyburn Field, Canada	20 ft	3 to 26%	0.01 to 500 md

	Yowlumne Field, California Waterflood (SS)	0 to 400 ft Avg. net 55 to 75 ft	15 to 20%	
	Texaco New Hope Shallow Unit, Franklin Co. TX Horizontal Injector Waterflood Project	18 ft	12%	2 md
EOR	Rainbow Keg River G Pool, Canada, Miscible	35 to 40 ft	10%	565 md
	Pembu Nisku Field, Canada, Miscible	130 to 330 ft	10 to 30 %	1.5 to 10 Darcies
	Chateaurenard Field, France Polymer	0 to 23 ft	30 %	800 to 3000 md 1600 md (avg)
	Cold Lake, Canada, Thermal	35 to 40 ft	10%	565 md
	Talnglflags North Field, Canada, Thermal	90 ft	33%	4 Darcies

SS = Sandstone
LS = Limestone

Table 1. Horizontal Well Applications

It is interesting to note that horizontal wells have been drilled in thin zones with thicknesses as small as 10 ft (3 m). As noted earlier, in some coal-bed methane reservoirs, horizontal wells have been drilled in even 5 ft (1.5 m) thick zones. Thus, horizontal wells have been drilled and are commercially successful in thin zones. However, if horizontal wells are drilled to produce oil and minimize water and/or gas production (coning application), then as seen in Table 1, the minimum zone thickness for a horizontal well application appears to be 15 to 20 ft (4.5 to 6 m) thick.

This is because, to reduce coning, it is essential to have certain stand-off (vertical distance) between the oil-water and or gas-oil contact and the horizontal well to prevent rapid breakthrough of water and or gas in a horizontal well (See Figure 5). Successful application of horizontal oil wells in water and gas coning situations requires at least 15 to 20 ft (4.5 to 6 m) thick oil columns which could provide at least 10 ft (3 m) of stand-off between the horizontal well and the oil-water and or gas-oil contact. Similarly, horizontal gas wells drilled to minimize water coning also require 10 to 15 ft (3 to 4.5 m) stand-off between the horizontal well and the gas-water contact. However, as noted earlier, if there is no coning problem, then one can drill a horizontal well even in 5 to10 ft (1.5 to 3 m) thin zones.

-
-
-

Bibliography

Bonner, Julie, (2007) "Multilateral Technology Then and Now," *E&P Magazine*, August 2007. [History of multilateral wells.]

Carr, T.R., Mason, E.P., and Feazel, C.T. (2003), *Horizontal Wells: Focus on the Reservoir*, 260 pp., Tulsa, OK, The American Association of Petroleum Geologists, USA. [Describes various geological environments where horizontal wells have been drilled.]

Elrod, Jeffrey P., (1997) "Horizontal Air Drilling Increases Gas Recovery in Depleted Zone," *Oil & Gas Journal*, June 30, 1997. [ANNOTATION]

Fritz, R.D., Horn, M.K., and Joshi, S.D. (1991), *Geological Aspects of Horizontal Drilling*, 560 pp., Tulsa, OK, Education Department of the American Association of Petroleum Geologists, USA. [Describes various geological aspects where horizontal wells are successful.]

Joshi, S.D. (1991), *Horizontal Well Technology*, 535 pp. Tulsa, OK, PennWell Publishing Company. [A complete summary of the technology involved in various aspects of horizontal and multilateral wells.]

Joshi, S.D. (2007), *Reservoir Aspects of Horizontal and Multilateral Wells*, 265 pp. Tulsa, OK, Joshi Technologies International, Inc. [Class manual from one day seminar presented at the Society of Petroleum Engineers (SPE) Annual Technical Convention and Exhibition, Anaheim, California, November 11-14, 2007.]

McCoy, A. W., Davis, F. A., Elrod, J. P., Rhodes, S. L. Jr., Singh, S. P., (1996) "Using Horizontal Well Technology for Enhanced Recovery in Very Mature, Depletion Drive Gas Reservoirs --- Pirkle #2 Well, A Case History, Carthage (Lower Pettit) Field, Panola county, Texas," presented at the SPE Annual Technical Convention and Exhibition in Denver, Colorado, October 6-9, 1996. [A case history of a horizontal well drilled in a depleted gas reservoir.]

O'Driscoll, K.P., Amin, N.M., Tantawi, I.Y., (2000) "New Treatment for Removal of Mud-Polymer Damage in Multilateral Wells Drilled Using Starch-Based Fluids," SPE Drilling and Completion, September 2000, p.167. [Description of multilateral wells drilled in the United Arab Emirates.]

Schuh, Frank J., (1989) "Horizontal Well Planning-Build curve Design," paper SPE 20150-MS presented at the SPE Centennial Symposium at New Mexico Tech, October 16-19, 1989. [ANNOTATION]

Singhal, A.K., Springer, S.J. (2004), "Some Lessons on Application of Horizontal Wells from the Western Canadian Experience," paper SPE 89372 presented at the SPE/DOE Improved Oil Recovery Conference, Tulsa, OK, April 2004. [ANNOTATION]

SPE Reprint Series No. 33 (1991), *Horizontal Drilling*, 230 pp. Richardson, TX, Society of Petroleum Engineers. [A compellation of magazine articles and technical papers presenting a thorough examination of horizontal drilling].

SPE Reprint Series No. 47 (1998), *Horizontal Wells*, 236 pp. Richardson, TX, Society of Petroleum Engineers. [A compellation of magazine articles and technical papers presenting a thorough examination of horizontal well technology].

SPE Reprint Series No. 54 (2002), *Underbalanced Operations*, 234 pp. Richardson, TX, Society of Petroleum Engineers. [Thorough study of underbalanced operations complete with case histories.]

Vo, D.T. and Madden, M.V., (1994) "Performance Evaluation of Trilateral Wells: Field Example," paper SPE 28376 presented at the SPE Annual Technical Conference and Exhibition, New Orleans, Louisiana, September 25-28, 1994. [Performance evaluation of multilateral wells].

Biographical Sketch

Sada Joshi is President of Joshi Technologies International, Inc., (JTI) of Tulsa, Oklahoma (USA). Dr. Joshi founded JTI, an oil and gas production company, in 1988. The company owns and operates oil fields in the United States of America; Colombia, South America; Canada and India. In addition to the home office in Tulsa, Oklahoma, JTI has offices in Ahmedabad, India, and Bogota, Colombia.

In the past 20 years, Dr. Joshi has been a consultant on over 200 horizontal well field projects around the globe involving over 1000 horizontal wells. Considered one of the foremost authorities on horizontal well technology by the petroleum industry, he has delivered over 100 lectures and short courses in over 20 countries. He is the author of the best-selling book, *Horizontal Well Technology*, published in 1991, as well as numerous technical papers published in several industry journals. For the 1995-96 season, Dr. Joshi served as a Distinguished Lecturer for the Society of Petroleum Engineers. At the beginning of 2000, the *Oil & Gas Investor*, through Hart Publications, honored "100 Most Influential People of the Petroleum Century," and Dr. Joshi was included on that distinguished list. In 2003, he received a distinguished alumni award from Indian Institute of Technology in Mumbai, India. Dr. Joshi holds a Ph.D. Degree in Mechanical Engineering from Iowa State University, Ames, Iowa, and obtained a B.S. Degree in Mechanical Engineering from W.C.E. College in Sangli, India and M.S. Degree from Indian Institute of Technology in Mumbai. He is a member of the Society of Petroleum Engineers, Canadian Institute of Mining, American Association of Petroleum Geologists, American Society of Mechanical Engineers, Tulsa Chamber of Commerce and Indo-American Chamber of Tulsa.