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Horizontal Drilling—A Global Perspective

Philip H. Stark

IHS Energy Group, Denver, Colorado, U.S.A.

ABSTRACT

Horizontal drilling has become a key technology used to reduce costs and enhance recoveries from producing reservoirs. Through 2001, commercial databases contained records on 34,777 horizontal wells from 72 countries. Canada (18,005 wells) and the United States (11,344 wells) were the leading countries for horizontal drilling. More than 5400 horizontal wells were recorded outside of North America. Russia, Venezuela, Oman, United Arab Emirates, Nigeria, Saudi Arabia, and Indonesia were the leading countries in terms of numbers of wells.

Although the concept of horizontal drilling emerged in the 1920s, economic viability was not demonstrated until the 1980s, when pilot projects at Rospo Mare field in Italy (1982) and Prudhoe Bay field (1984) and in the Austin Chalk of Texas (1985–1987) achieved three- to fourfold productivity increases with less than twofold cost increases. From a base of 51 wells in 1987, horizontal drilling increased rapidly; it expanded to the world's active producing provinces and peaked during 1997 with 4990 wells.

Horizontal drilling, which increases wellbore exposure to the reservoir, has delivered multiple benefits. Operators have used horizontal wells to revive economic production, to increase and speed recoveries, to reduce costs, and to increase rate of return. These benefits are critical for operators that must cope with increasing competition and volatile oil prices. The objective of this paper is to characterize the global geographic and geologic distribution of horizontal wells and to illustrate some of the benefits of horizontal drilling with examples from key fields and trends.

DATA SOURCES AND METHODOLOGY

Because of their global coverage, IHS Energy Group databases and reports were used as the primary sources of statistical and technical data in preparing this paper. A joint 1990 study (Horizontal Wells: Global Survey, Case Histories and Strategies) prepared by Erico Petroleum Information Ltd. and MRI, Ltd., is the source for reservoir and geologic aspects cited. Commercial database sources are not complete. Limited records have been reported from former Communist-bloc countries and from heavy-oil development projects in Venezuela. Other countries, such as Saudi Arabia, do not release individual well records, and the completeness and accuracy of reported horizontal-well records varies from region to region. Many horizontal-well records from the U.S. Gulf of Mexico, for instance, do not report reservoir formation names. Most of the charts and graphs in this paper were custom-generated from IHS Energy Group databases and therefore are subject to these limitations. Nevertheless, the magnitude and scope of coverage of these sources provide a representative framework that allows characterization of the global geographic and geologic distribution of horizontal wells and their benefits.

HORIZONTAL DRILLING WORLDWIDE

Horizontal-well distribution

After a modern rebirth during the early 1980s, horizontal drilling has been used to reduce costs and enhance recoveries in producing reservoirs worldwide. As shown in Table 1, through 2001, IHS Energy Group databases contained records for 34,777 horizontal wells in 72 countries. Canada recorded the most horizontal-drilling activity, with 18,005 (including original and redrilled boreholes). The United States ranked second in drilling activity, with 11,344 horizontal wells. More than 5400 horizontal wells were reported outside of North America. Through May 1999, horizontal wells had been drilled in 2322 producing fields; more than half (1235) were in the United States, where operators tried horizontal completions in a variety of fields and reservoirs. Canadian operators appear to have been more selective in choosing their targets, as shown by the relatively high percentage of fields in which 10 or more horizontal wells were drilled. Operators were not summed in Table 1 because of the large number that drilled horizontal wells in more than one of the regions.

Horizontal wells have been drilled throughout the world's leading producing provinces. The map in Figure 1 shows the global distribution of 20,430 original horizontal wells (8998, United States; 8221, Canada; 3211, rest of the world) completed through May 1999. (The map does not include horizontal legs that were drilled from prior vertical boreholes.)

History

Although horizontal drain holes emerged in the 1920s, technological development was slow, and the practice was seldom used. In the 1950s, use of horizontal drilling was still limited to very short-radius (~50 ft.) drain holes in shallow, unconsolidated reservoirs. However, during the late 1970s and early 1980s, several factors—including access to enhanced horizontal technologies from the former Soviet Union; positive results in drilling long-radius, deviated wells from offshore platforms; and higher oil prices—helped trigger renewed interest in horizontal drilling. Pilot projects by Elf Aquitaine during 1982 at Rospo Mare field in Italy (Bosio, 1990); by British Petroleum and ARCO in 1984 at Prudhoe Bay field in Alaska (Montgomery, 1990a); by ARCO in 1996–1997 at Bima and Arjuna fields in Indonesia; and by Oryx, Mobil, Amoco, and Union Pacific Resources in 1985–1987 in the Austin Chalk trend of Texas (Montgomery, 1990b) finally demonstrated the economic viability of horizontal drilling. From a base of 51 wells in 1987, horizontal drilling increased rapidly in the world's active producing provinces and peaked during 1997, when more than 4000 wells were completed.

Benefits

Horizontal drilling, which fundamentally increases wellbore exposure to the reservoir, has delivered multiple benefits. Operators have used horizontal wells to revive economic production and to increase recovery from old producing fields. Horizontal wells also have been used to speed recovery and increase rate of return—a primary driver for North American projects. Other operators have used horizontal wells to reduce capital and operating costs significantly or to minimize the drilling/production operations impact and possible damage to fragile environments. Outside North America, maximizing total return (through enhanced reservoir management, maximizing recoveries, and minimizing long-term costs) has been a primary driver for using horizontal-drilling technologies. These benefits are critical to operators who must compete in an era of chronic, excess oil supplies and low or volatile oil prices.

Horizontal- and extended-reach wells have been drilled to address various reservoir, economic, and geologic aspects. The characteristics of eight important reservoir and/or economic aspects are listed in Table 2. Seven important geologic and reservoir types that are prime horizontal-drilling targets are listed in Table 3. These characteristics have yielded positive results in horizontal-well completions.

Table 1. Global horizontal-well counts. Well counts are as of December 31, 2001. Field and operator counts are through May 1999. (Source: IHS Energy Group databases.)

Country	*Wells*	*Fields*	*Fields >10 wells*	*Operators*
Canada	18,005	1235	94	994
United States	11,344	294	69	300
Rest of world	5428	693	64	306
(72 countries)	***34,777***	***2322***	***227***	

HORIZONTAL DRILLING IN THE UNITED STATES

The success of horizontal wells in the fractured Upper Cretaceous Austin Chalk trend in Texas and Louisiana sustained high levels of horizontal-drilling activity in the United States through 1998. As shown in Figure 2, 4230 horizontal wells were completed in the Austin Chalk trend through May 1999. Collectively, these wells generated 6887 completions, which indicates a proliferation of wells with multiple laterals.

Other leading historic reservoir targets include heterogeneous and/or fractured-carbonate reservoirs in the Ordovician Red River in North Dakota, the Permian San Andres and Devonian in the Permian Basin in west Texas, and the Lower Cretaceous Buda limestone in central Texas. Horizontal wells have been used to increase productivity while controlling water and gas coning in the Triassic Sadlerochit sandstone reservoir at the Prudhoe Bay Field in Alaska. The early hope that horizontal wells would yield improved recoveries at Prudhoe Bay, however, has not materialized. Standing (2000) showed that

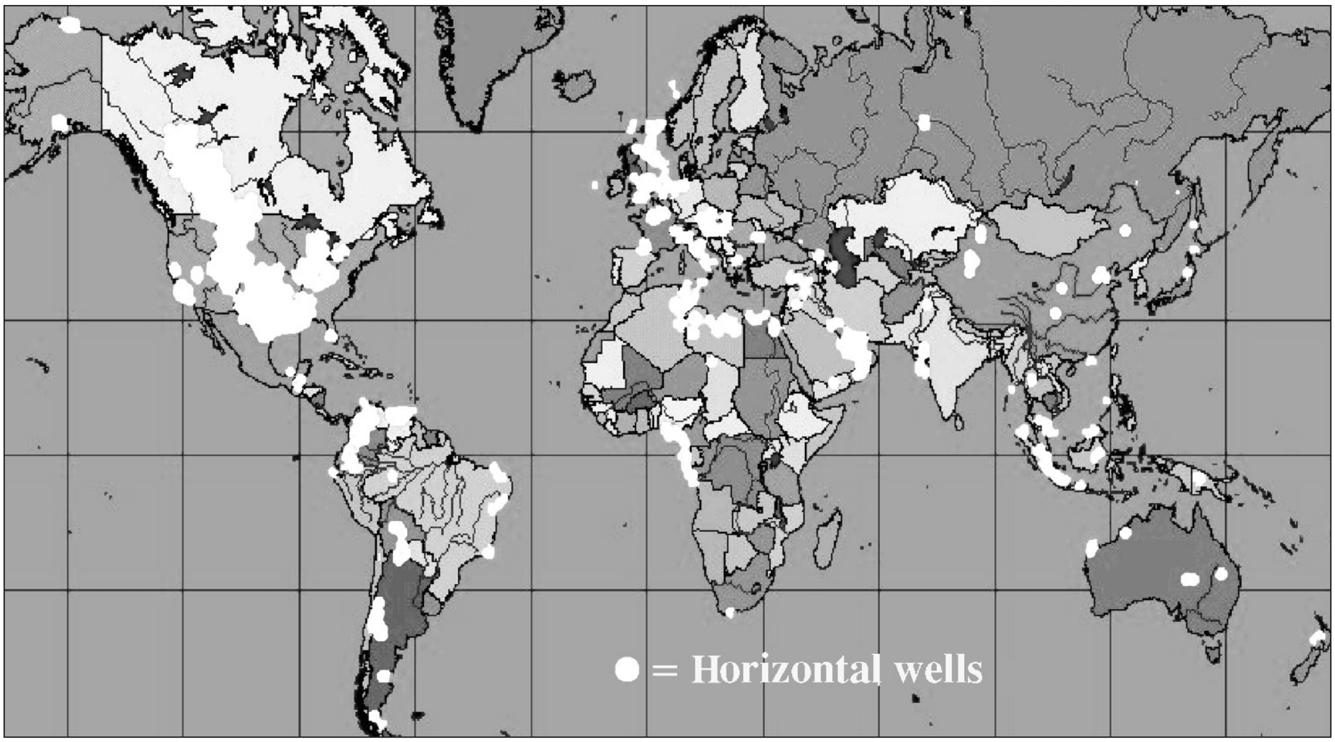

FIGURE 1. Global distribution of horizontal wells through May 1999. (Source: IHS Energy Group databases, May 1999.) This map shows only new wells drilled from the surface with horizontal borehole legs for which latitude-longitude coordinates were available. Only two new countries, Jordan and Vietnam, have reported horizontal wells since this map was generated.

TABLE 2. HORIZONTAL DRILLING PLAYS: RESERVOIR/ECONOMIC ASPECTS.

Characteristic	*Field/area example*
Coning	Prudhoe Bay (Alaska)
Thermal recovery	Belridge (California)
Waterflood	Weyburn-Estevan (Saskatchewan)
Thin beds	Cedar Hills (South Dakota)
Slot limitations (cost)	Dan (Denmark offshore)
Environment	Prudhoe Bay (Alaska)
Limited compartment	Uracoa (Venezuela)
Tar sands	Hamaca (Venezuela)

Sources: Fjeldgaard, 1990; Montgomery, 1990a, b, c, 1995, 1996; MRI Ltd. et al., 1990.

TABLE 3. HORIZONTAL DRILLING PLAYS: GEOLOGIC ASPECTS

Reservoir type	*North American examples*
Source rocks	Bakken Shale (North Dakota)
Fractured chalk	Austin Chalk (Texas)
Stratigraphic traps	Niagara Reef (Michigan)
Paleokarst reservoirs	San Andres/Yates (Texas)
Thin beds	Red River (North Dakota)
Tight-gas formations	Appalachian Basin
Heterogeneous sands	Tulare Formation (California)

Sources: Montgomery, 1989, 1990a, b, 1995, 1996; MRI Ltd. et al., 1990.

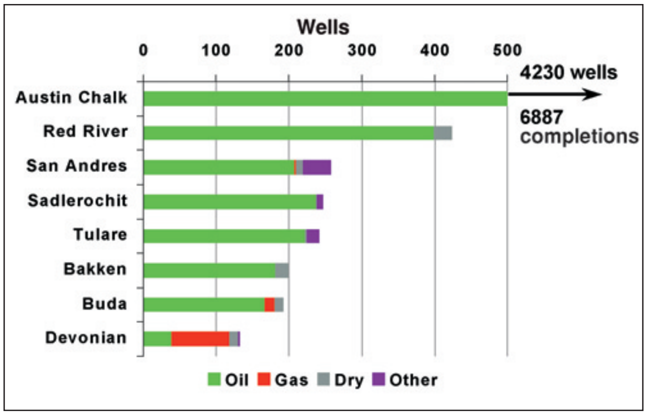

FIGURE 2. Leading horizontal-well formation/reservoir targets in the United States through May 1999. (Source: IHS Energy Group databases, May 1999.)

Prudhoe Bay horizontal wells produced at higher rates in their early years, but may not yield more ultimate recovery than neighboring vertical wells. Horizontal wells also are used to produce oil from heterogeneous upper Miocene Stevens turbidite sandstone (Kuespert et al., 1992) and Pleistocene Tulare reservoirs in California. Late Devonian Bakken shale source rocks in North Dakota's Williston Basin were targeted from 1988 through 1994 in a significant horizontal-drilling play. The Niagran reef trend in the Michigan Basin also has been a prime horizontal-well target. All but the Sadlerochit sandstone and Bakken shale continued to be active horizontal-well targets through 1999 and 2000.

The abundance and importance of horizontal drilling in offshore Gulf of Mexico should not be overlooked. Approximately 210 horizontal wells were drilled in this province through May 1999 but were not included in the chart in Figure 2 because the wells were completed in multiple Pleistocene and Tertiary Pliocene and Miocene reservoirs. Christensen et al. (1999) pointed out that horizontal wells were successful in exploiting oil rims, bioturbated sands, and stratigraphic compartments and in accelerating production to reduce life-cycle costs. Highly layered, low net-to-gross-pay reservoirs, however, were not found to be good candidates for horizontal wells.

Although fractured- and heterogeneous-carbonate reservoirs have been the primary horizontal-drilling targets in the United States, horizontal drilling has been applied to most of the reservoir, economic, and geologic aspects identified in Tables 2 and 3. Moreover, horizontal wells have been drilled in virtually all U.S. producing regions, as shown on the map in Figure 3. Key reservoir trends that have been the focus of horizontal-drilling programs are marked on the map, including Canada's leading field for number of horizontal wells, the Weyburn-Estevan field in southeastern Saskatchewan. The main fairway for Devonian horizontal wells is in west Texas. In central Texas, early Cretaceous Buda carbonates have been drilled horizontally in and along the Austin Chalk fairway. The Permian San Andres fairway runs north to south along the Central Basin Platform and west of the Devonian trend.

AUSTIN CHALK TREND

The Austin Chalk trend has undergone three development cycles during the last 60 years, and horizontal drilling has played an integral role in the latest development cycle. The benefit of using horizontal-drilling technology in this area is apparent from a comparison of recoveries from vertical wells in the second cycle, which was triggered by increasing oil prices during the late 1970s, and by recoveries in the most recent cycle, which was triggered by horizontal-well success. At the Pearsall field in the southwest part of the Austin Chalk trend (P on the map in Figure 3), the horizontal-well productivity index ranged from 2.7 to 4.7 (mean = 3.75) times greater than the production from vertical wells drilled during the second cycle. Giddings field, located near the northeast end of the Austin Chalk fairway in east central Texas (G on

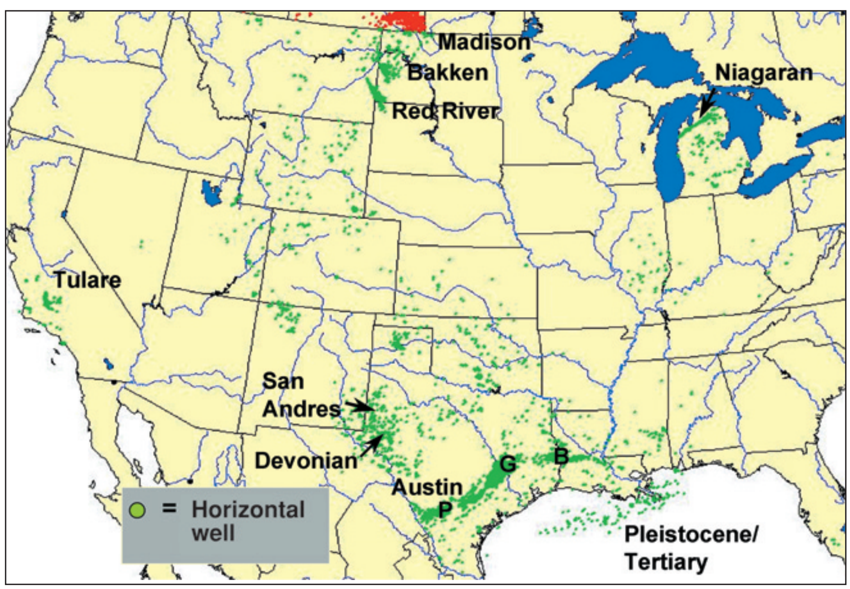

FIGURE 3. Map showing horizontal wells in the United States and southern Canada. Data extracted from IHS Energy Group databases as of May 1999. Leading reservoirs and fields for horizontal wells are annotated. P = Pearsall field; G = Giddings field; B = Brookeland field.

the map in Figure 3), produced 381 MMBOE from 2749 vertical wells during the second cycle (1979–1989). The latest cycle yielded an additional 605 MMBOE through 1998 from 2317 horizontal wells that have been completed since 1990. Figure 4 shows annual oil and gas production for Giddings field and illustrates the relevance of the recent horizontal-drilling cycle.

Since 1994, gas production at Giddings field has increased from downdip extension of the field, where horizontal wells yielded large production rates (20 MMCFD to 30 MMCFD) from deep, overpressured Austin Chalk. Horizontal wells also are being used to extend Austin Chalk production into Louisiana, where parts of the reservoir must be tapped below 15,000 ft. Prevailing high oil and gas prices likely will be required to stimulate continued drilling in this part of the trend.

Stark (1991, 1992) and Fritz (1991) provide additional information about the performance of the Austin Chalk and other United States horizontal-drilling plays and potential reservoir targets.

HORIZONTAL DRILLING IN CANADA GAINS MOMENTUM

As shown in Table 1, Canada ranks first in total number of horizontal wells reported as of December 2001. Canadian operators have led the world in annual horizontal-drilling activity since 1993, and they recorded a peak of 2814 horizontal wells during 1997. This compares with the peak U.S. count of 1383 horizontal wells, also recorded during 1997.

Horizontal completions have been used to exploit key reservoirs throughout the western Canadian sedimentary basin. Principal targets include the widespread Early Cretaceous Manneville Group sandstones, the Mississippian Madison Group carbonates, and Middle and Late Devonian carbonates, several of which produce from reefs. Eight of the top 10 fields (ranked by number of horizontal wells), including the well-known Athabaska and Cold Lake heavy-oil deposits, produce from Early Cretaceous sandstones. Farquharson et al. (1992) summarized early horizontal-drilling developments in many of these reservoirs.

The top-ranked field, however, the Weyburn-Estevan field in southeastern Saskatchewan, produces from Mississippian carbonates. This field provides an excellent example of combining horizontal-well technology and waterflooding to increase productivity. For purposes of comparison, production histories for 250 vertical wells and 250 horizontal wells were extracted from the same sector of the Weyburn-Estevan field. These production histories were normalized to the same start date and projected. Results indicated that the average vertical well would yield 395.7 MBO and 59 MMCFG, compared with 1027.6 MBO and 196.6 MMCFG from the average horizontal well. A normalized production-decline plot that includes 250 horizontal wells in the Weyburn-Estevan Field is shown in Figure 5.

Martin (2000) analyzed production in 12 western Canadian pools and found that horizontal wells achieved a first-year average productivity improvement factor (PIF) of 6.08 compared with vertical wells in the same reservoir. He also showed how peak and total first-year production could be used to provide insight concerning ultimate horizontal-well recoveries. Such positive results continue to stimulate Canadian horizontal drilling.

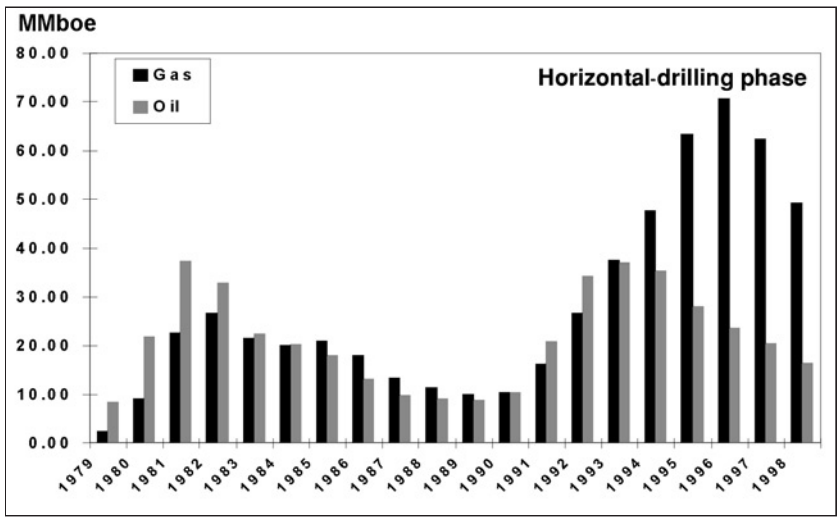

FIGURE 4. Austin Chalk oil and gas production, Giddings field, 1979–1998. Oil is in black, gas in gray.

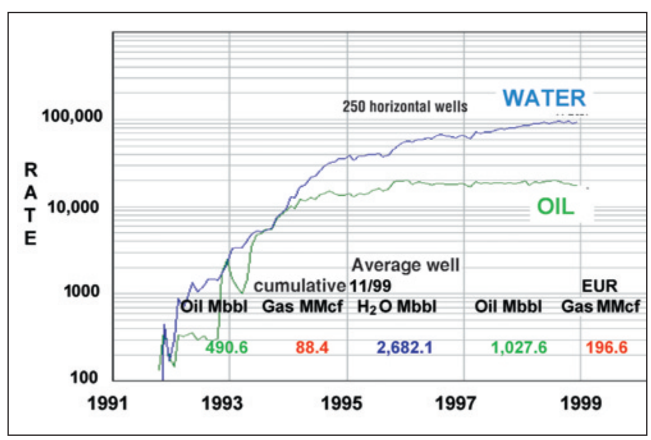

FIGURE 5. Normalized production-decline plot of 250 horizontal wells, Mississippian Madison Group, Weyburn-Estevan field, Saskatchewan, Canada. EUR = estimated ultimate recovery.

HORIZONTAL DRILLING IN THE REST OF THE WORLD

Horizontal-drilling and completion techniques also have been applied widely and successfully in most of the important producing basins and fields throughout the rest of the world. Outside North America, IHS Energy Group records indicate that approximately 5400 horizontal wells have been drilled in more than 700 fields that are credited with 450,000 MMBO of remaining reserves. If Ghawar and other Saudi Arabian fields with active horizontal-well development programs are added, the total oil reserves being produced at least in part by horizontal wells could exceed 600 billion bbl.

The leading countries (excluding the United States and Canada) for horizontal-drilling activity through June 2000 are shown in Figure 6. Venezuela, Oman, the United Arab Emirates, and Nigeria were the leading countries for which individual well records are reported. R. A. Kamal (personal communication, 2000) noted that Saudi Aramco has drilled more than 200 horizontal-development wells, in which case Saudi Arabia would rank fifth in horizontal-drilling activity, just ahead of Indonesia, which reported 212 horizontal wells. New information (Matlashov and Ustinov, 2001) indicates that 1177 horizontal wells were drilled in Russia through 2001. Peak activity was reported during 2000, when 198 horizontal wells were drilled. Based on this information, Russia vies with Venezuela as the leading country for horizontal drilling outside North America.

Four of the leading fields for horizontal-well drilling outside North America, as reported through June 2000, are in Venezuela. Three of these fields, Hamaca, Uracoa, and Melones, produce from the prolific early and middle Miocene Oficina sandstone reservoirs. Lagunillas, the fourth Venezuelan field, is part of the giant Bolivar Coastal fields complex in Lake Maracaibo. Other leading fields, including Yibal in Oman and Zakum in the United Arab Emirates, use horizontal wells to exploit prolific carbonate-platform reservoirs. The Nimr field in Oman, the Rabi-Kounga field in Gabon, the Bab field in the U.A.E., and the Attaka field in Indonesia's Kutei Basin round out the list of leading fields for numbers of horizontal wells.

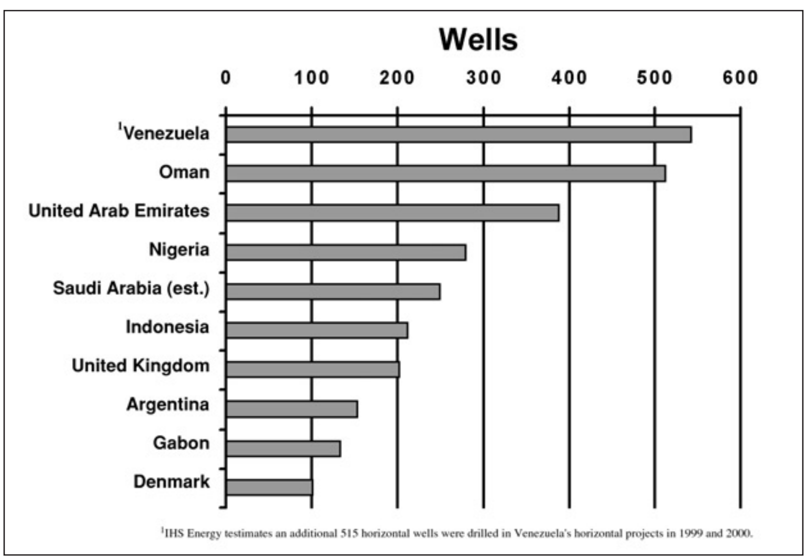

FIGURE 6. Horizontal wells—leading countries outside North America through June 1999. (Source: IHS Energy Group databases, June 2000.) Saudi Arabia well count is estimated.

EXAMPLES FROM KEY FIELDS AND TRENDS

The following examples illustrate the diversity of reservoir conditions in which horizontal wells have made positive contributions:

- Elf Aquitaine achieved early and pivotal economic success with its horizontal-well experiments at the Rospo Mare field in Italy during the early 1980s. The Early Cretaceous karsted-carbonate reservoir at Rospo Mare contains heavy, 11° API-gravity oil. The horizontal-well program (21 wells) helped to boost oil production from approximately 2000 BOPD in 1986, to a peak of nearly 29,000 BOPD in 1990. Cumulative oil production hit 68.1 MMBO in 1997.
- The Dan field in the Danish offshore sector provides an interesting comparison and contrast to Austin Chalk reservoirs in the United States. The Early Cretaceous Dan Chalk reservoir records 28% porosity and 0.5 md permeability. Reported reserves are 645 MMBOE and 860 bcfg. Most horizontal boreholes radiate from the center of the nearly circular, faulted-domal structure. The 46-well horizontal program helped to boost production from approximately 60,000 BOPD in 1991 to more than 100,000 BOPD in 1998.
- The Hamaca area in Venezuela illustrates the use of horizontal wells and thermal (steam) processes to boost recoveries of heavy oil. Hamaca field is part of the well-known "Orinoco Tar Belt" and is estimated to contain 40 billion bbl OIP, with 5.6 billion bbl in recoverable reserves. The heavy, 7° API-gravity crude oil is trapped in a faulted and folded monocline near the southern limit of the fluviodeltaic early and middle Miocene Oficina sandstone reservoir. Recovering the heavy oil with vertical

wells is difficult, although the Oficina records 32% porosity and as much as 10 d permeability. Approximately 780 wells, including at least 205 horizontal boreholes, have been drilled in the Hamaca area. After the introduction of horizontal drilling at Hamaca field in 1993, production more than doubled, from 40,000 BOPD to approximately 90,000 BOPD in 1996. Horizontal wells at Hamaca field reportedly produced as much as 2000 BOPD when combined with steam injection.

- At Widuri field, Indonesia's largest offshore field in the West Java Sea, Maxus used 3-D seismic data to target fluvial channels in the upper Gita Formation (lower Miocene). The B-14 horizontal well established initial production at 7000 BOPD, approximately three to four times that of vertical wells in the same reservoir facies.

SUMMARY

Horizontal-drilling and completion technologies have been deployed successfully in a variety of reservoir and operating conditions throughout most of the world's producing provinces. Case histories indicate that horizontal completions generally enhance oil and gas productivity but do not necessarily increase total recovery. Benefits such as increased cash flow, lower development and producing costs, and reduced environmental impact should continue to drive the use of global horizontal drilling. Sharing of new horizontal technologies and completion practices should allow operators to continue to lower costs, to enhance recoveries, and to successfully deploy horizontal completions into additional conventional and unconventional reservoirs.

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