FUNDAMENTALS OF DRILLING

Technology and Economics

John L. Kennedy

# of Drilling

—*Technology and Economics*

John L. Kennedy

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This book is dedicated to the following persons, listed in the order of their initial influence on my life:

Russell and Wilma
Barbara
Patty
Jane
Anne

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Preface

DRILLING an oil or gas well is a complex operation. Though similar methods and equipment can be used in many wells, literally each well is different. Consequently, oil and gas well drilling has little in common with typical industrial production-line operations.

This overview of the common techniques, the equipment, and some of the problems involved in drilling oil and gas wells is designed to familiarize those persons not directly involved in drilling operations with the industry and its capability. In addition, it explains some common industry terms and relationships and offers perspective on the tremendous cost of oil and gas well drilling. The book also indicates the diverse skills that must be combined to drill a single well. Extrapolate this complexity to the tens of thousands of wells drilled around the world each year—some under the most difficult conditions imaginable—and the remarkable accomplishments of the industry will become apparent.

This book is not a drilling operations manual or a source of well design information. If design and operations techniques were detailed for many individual aspects of drilling, an entire book would be required for each subject. Instead, the text provides information that will help clarify basic drilling procedures without complicating the subject with data only a drilling engineer could profit from.

Much has been written on all phases of the drilling operation, and design and operating detail is available on almost any subject discussed in the following pages. A sampling of these sources is contained in the references following each chapter.

It is hoped that, in addition to answering many questions, this book will spark an interest in learning more about oil and gas well drilling.

Contents

1 The Oil and Gas Well Drilling Industry

OIL and gas well drilling has continued to yield to the march of technology with sophisticated equipment and computer analysis of drilling variables an accepted part of today's drilling operation. But there is still a considerable amount of art involved in drilling a hole to a depth of more than four miles and then installing equipment in it while not being able to see what is being done. Drilling crews perform complex operations thousands of feet down to set tools or to remove them from the hole, guided only by their experience in analyzing a variety of gauges and conditions at the surface. Even so, today's drilling technology is the result of only a few dramatic innovations; continued steady evolution is responsible for most of the advance made in the last 100 years.

It is impossible, of course, to say precisely what new techniques and equipment will become a part of routine drilling in the next two decades. But it is likely that most will still be the product of evolution rather than the result of a dramatic new direction. As this evolution continues, the drilling operation will involve more and more applied science. But, as will be apparent after reading this basic outline of oil and gas well drilling, successful drilling will never be possible without at least a little art. Performing a critical operation with a tool on the end of a dangling string of drill pipe 20,000 ft long in a hole that may be no larger than a residential air-conditioning duct will continue to demand more than just skill.

A brief history

Almost as far back in history as one wants to go, there is evidence that holes were dug into the earth for a variety of purposes using the tools

available at the time. Though not the earliest example, brine wells apparently were drilled in China around 600 B.C.[1] One analysis of records estimates that as early as 1200 A.D. wells may have been drilled as deep as 1,500 ft. Much more detailed accounts of these ancient drilling efforts are available.[2]

But a good reference point for beginning a brief look at the development of modern drilling methods is the Drake well, drilled by Colonel Edwin Drake in Pennsylvania in 1859. Though not a deep well—total depth was 69 ft—and not a highly productive one at about 20–30 b/d by pump, it is significant for two reasons. First, it is considered by many to be the first commercial oil well. Second, it was drilled with equipment that would become the standard for many years to come: the cable tool rig.

Cable tools. Cable tool rigs make hole by raising the bit with a system of wheels and cables and then dropping it, punching the hole deeper. These rigs were the workhorses of the oil and gas drilling industry for almost a century. They drilled most of the wells and found large reserves of oil and gas. But they began to be replaced with rotary drilling rigs in the early part of of the 20th century, and after World War II continued to give ground to the rotary rig.

Rotary rigs. The rotary rig drills the bulk of oil and gas wells today. A rotary drilling machine was patented in 1845, but its most significant commercial debut was in 1901 when it was used to complete the Spindletop well near Beaumont, Texas. The rig was brought in on the Spindletop well after several attempts to drill with a cable tool rig were unsuccessful because of running quicksand. With the rotary drilling equipment, this troublesome zone could be drilled and isolated with casing.

Rotary rigs make hole with a boring action rather than punching a hole as the cable tool rig does. A bit rotates while it is in constant contact with the rock at the bottom of the hole. Part of the weight of the drill pipe above the bit rests on the bit while it is rotating to force it into the rock as it turns. Fluid pumped down the drill pipe and back to the surface removes rock cuttings from the hole.

The share of oil and gas well drilling done by rotary drilling equipment has continued to increase steadily since the 1940s. Today, rotary rigs (Fig. 1–1) drill most oil and gas wells.

The basic concept of rotary drilling—rotating a bit on the bottom of the hole with a length of drill pipe through which fluid is circulated to remove cuttings—has not changed significantly in more than 75 years.

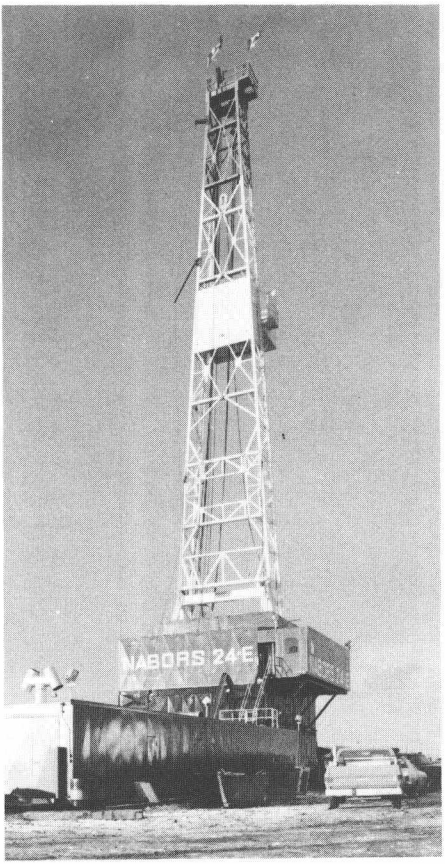


Fig. 1–1 Modern land drilling rig. (courtesy Oil & Gas Journal*)*

But there have been many improvements in the equipment comprising these rigs. These improvements have brought greater efficiency, greater depth capability, and more control over hole conditions and reservoir fluids. And new tools have been developed to supplement the basic rotary drilling machinery.

One of the most significant advances was the rolling cutter rock bit. It was designed, built, patented, and used by Howard Hughes in 1909. Early bits of this type underwent considerable revision, but the roller bits used today are quite similar to those used a half century ago. The concept is the same, but vast improvements have been made in design, metallurgy, and components. Today's bits last many times longer than those early bits did, and the variety of available types makes the roller cone bit applicable to almost all formations.

In recent years, development has focused on making bits match the characteristics of the rock they will be drilling. Many modern bits are designed to drill a variety of formation types.

Other equipment used for the rotary drilling operation has been greatly improved. Circulating systems have greater capacities and can be much more precisely controlled. Drilling fluids have been formulated using complex chemistry to combat specific downhole problems. The chemical and physical properties may even be adjusted several times while drilling a single well. Drill pipe metallurgy has been improved to combat corrosion and to withstand the stresses resulting from extreme temperatures, pressures, and depths. Pipe handling tools and downhole equipment have been developed to meet specific needs. For example, in offshore drilling where handling heavy equipment on a floating vessel is dangerous, automatic pipe handling systems have been developed. Downhole tools to permit cementing casing and performing other jobs in extremely deep wells are other examples of this development.

But rotating the bit while it is in contact with the rock at the bottom of the hole and circulating fluid through the drill string to remove cuttings is still the way oil and gas wells are drilled today.

Other approaches. This is not to say considerable time and money have not been spent in an attempt to find a better way to drill. Several changes in the basic concept of rotary drilling have been studied, and some have been field-tested. To date, however, they have not been competitive with the conventional rotary drilling technique.

Two of these techniques, high-pressure water jetting and abrasive jetting, still use mechanical energy to remove rock from the bottom of the hole. However, they are significant departures from the conventional rotary method because of the specially designed equipment needed. Both of these approaches have been field-tested with some success, but neither is in routine drilling use.[3]

Other approaches to drilling oil and gas wells have been studied but are still not in commercial use. These include:

1. electric arc and plasma drills that melt, spall, or thermally degrade the rock
2. electron beam drills that melt and vaporize the rock
3. explosive drills that shatter the rock formation
4. laser drills that melt or vaporize the rock

Even more exotic ways to remove rock have been studied, but none can yet compete with the conventional rotary drilling process in 'round-

the-clock drilling under tough field conditions. Many changes will be made in drilling methods in the next two decades, but there is little evidence that any conceptual change in today's rotary drilling technique will make a significant contribution in the near future.

Offshore drilling

Although the method used to drill a well in the ocean floor is similar to that used to drill a well on land, special equipment is needed to support the rig above the water. Because of this, offshore drilling has become almost a separate industry with an impressive, though short, history of its own.

Wells were drilled over water from a pier at Santa Barbara, California, as early as 1897. In 1911, a steam-powered rotary rig drilled from a wooden platform in Caddo Lake, Louisiana. And in 1933, a drilling rig mounted on a barge drilled in Lake Pelto, Louisiana. The modern offshore drilling industry got its real start in 1947 when the first well was drilled out of sight of land by Kerr-McGee Corp. in Ship Shoal Block 32 in the Gulf of Mexico. In the few years that followed, technology developed rapidly. In 1955, drilling was performed from a drillship, a ship-shaped vessel on which a rotary rig was mounted.

The capability of the industry to explore and develop oil and gas reserves in the oceans of the world was apparent by 1957 when a well was drilled in 100 ft of water. The technology needed to drill in that water depth pales beside today's deep-water drilling technology. The equipment used a short 25 years ago seems primitive compared with the sophisticated offshore drilling units of today (Fig. 1–2).

In a mere quarter of a century, the offshore drilling industry has developed drilling vessels and support equipment that make it possible to drill in water depths of several thousand feet. In 1979, for example, Texaco Canada Resources Ltd. drilled an offshore well in 4,875 ft of water off Newfoundland.[4] That record was expected to be challenged in 1982 in the Mediterranean.

Limited experimental drilling operations have been conducted in much greater water depths. In 1970, the Deep Sea Drilling Project reentered a hole drilled in 13,000 ft of water in the Caribbean.[5] A hole was drilled to 2,300 ft below the ocean floor with the first bit; then the hole was located and reentered and another 200 ft was drilled with the second bit.

Although commercial oil and gas well drilling has not been done in water nearly this deep, this achievement was significant. It demon-

strated the ability to reenter a hole in very deep water. Reentry is a key to successful deep-water drilling.

The water depths in which oil and gas can be produced are less than the depths in which the industry can drill. At present, technology is not available to produce from water depths of 5,000 ft, for instance. But that technology could be developed from existing hardware if large hydrocarbon reserves are expected and if the economics are favorable.

Production technology is constantly being developed for deeper water and for more severe environments. For example, fixed production platforms, still the industry's preferred method of producing offshore fields, have been installed in 850 ft of water offshore California and in 1,025 ft of water in the Gulf of Mexico. Another fixed platform was being built in 1981 for installation in the Gulf of Mexico in 935 ft of water. These and other fixed platforms for more modest water depths support oil and gas producing equipment above the water's surface. Platforms that reach above the water's surface but are not rigidly fixed to the ocean floor are also under development. This compliant approach to platform design includes tension-leg platform structures. The maximum water depth in

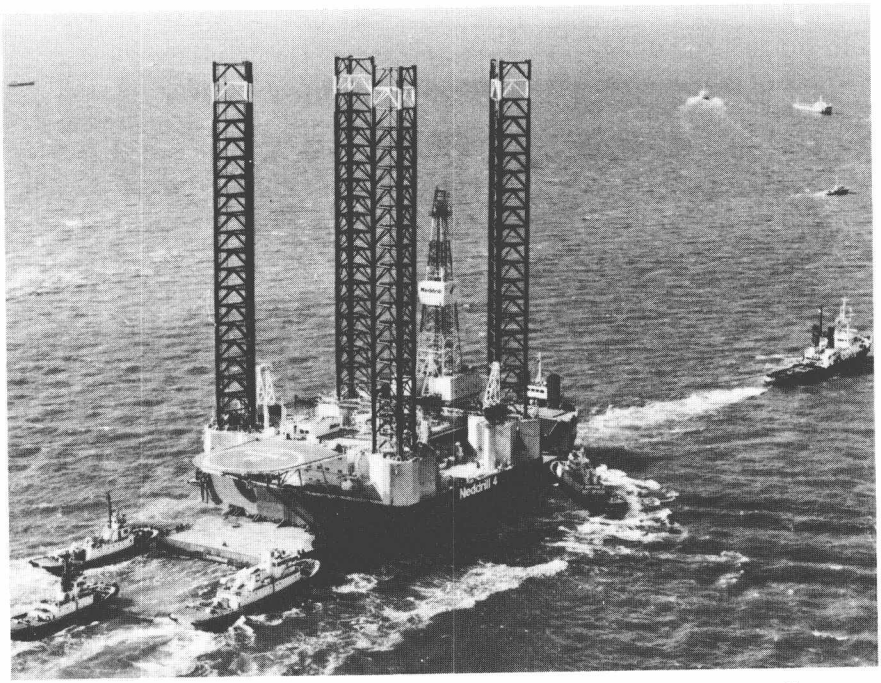


Fig. 1–2 Modern offshore mobile drilling rig. (courtesy Oil & Gas Journal*)*

which fixed platforms can be installed is estimated to be 1,200–1,500 ft, while the tension-leg platform might extend platform capability to water depths of several thousand feet.

Subsea completions. There is yet another approach to producing oil and gas in deep water: the subsea completion. When a well is completed subsea, the wellhead and associated valves are installed on the ocean floor and the well is connected to production facilities with a submarine pipeline.

Subsea completion systems range from a single wellhead to complex ocean floor templates through which a number of wells would be drilled directionally and connected to the template. More complex systems have been proposed that would let personnel service wells and equipment on the ocean floor in a dry environment.

Most operating subsea completions, however, are single wells located in water depths up to about 400 ft. A few have been installed in water as deep as 600 ft. About 140 subsea completions had been installed around the world by 1978.[6]

Equipment development. Early offshore drilling was done by mounting land drilling equipment on some sort of makeshift platform to support it over the water. To operate in the water depths the industry needed to reach, platforms and vessels designed specifically for supporting offshore drilling operations had to be developed.

From these early makeshift platforms, equipment evolved into sophisticated steel jackup rigs with legs that can support the platform above the water in depths to 300 ft and more. The modern semisubmersible rig, which does not have to depend on legs resting on the ocean bottom for support, can drill in water depths up to several thousand feet. Special drillships were also developed for deep-water drilling in remote areas. These vessels have large storage capacities for pipe and supplies; some are self-propelled to speed the trip between locations and to eliminate the need for tow vessels.

Another example of the sophistication reached by the offshore drilling industry in its short history is the dynamically positioned drilling vessel. Developed for very deep water and special operations, such vessels can maintain a position over the well site while drilling without using anchors. A series of thrusters maintains position by responding to the commands of a position-monitoring system. A computer links the two main components of the dynamic-positioning system—monitoring equipment and thrusters. Such vessels are few because this capability is not often needed and holding the drilling vessel in position with a

conventional anchoring system is a less-expensive way to keep the vessel on location.

Continued growth. Tremendous reserves of oil and gas have been found offshore around the world.[7] Oil produced from offshore fields accounted for about 20% of world production in 1981, averaging about 12 million b/d. Worldwide offshore production of natural gas is about 25 billion cfd, roughly half of which is produced from U.S. offshore fields.

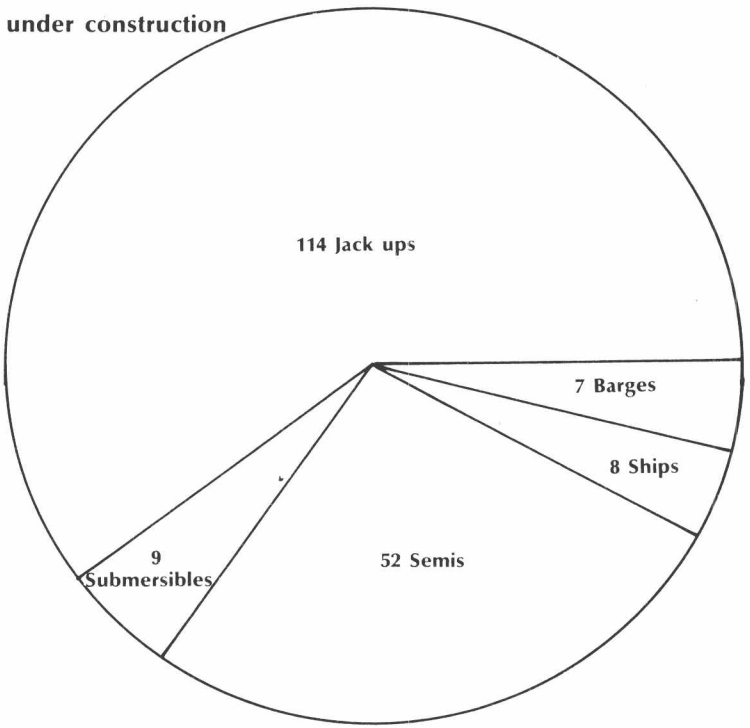
Several thousand wells are drilled offshore each year, and the mobile offshore drilling rig fleet (Fig. 1–3) included almost 600 operating units in early 1982. Another 128 new mobile offshore drilling units were under construction at that time.[8] In addition to mobile offshore drilling units, the industry had about 380 fixed platform rigs located around the world at the end of 1981.[9] Most forecasters feel the fleet will expand rapidly in the next decade as more offshore areas become available for exploration. Modest but steady growth is also expected in offshore oil and gas production during this period.

Development of offshore drilling equipment has been expensive. The cost of a modern deep-water floating drilling rig can be more than $100 million today, and the cost of drilling and completing a single deep-water offshore exploration well can be tens of millions of dollars. Besides the drilling rig itself, which remains on the well site until drilling is complete, the industry had to develop support equipment and services: diving, transportation for crews and equipment, and others. For example, a large fleet of tug/supply and crew/utility vessels now exists to serve offshore drilling and production operations. One estimate puts this support fleet at about 3,500 vessels worldwide.[10]

An industry expert says each mobile offshore rig must be serviced full time by about two offshore supply vessels, and a typical fixed production platform needs the services of one vessel. A sizable fleet of helicopters also supports offshore drilling and production operations, primarily transporting personnel between the platforms and shore bases.

To bring the oil and gas found offshore to market required the development of an offshore pipeline construction capability. Like the offshore drilling industry, offshore pipeline construction is highly specialized. Pipe-laying barges and associated equipment used to build offshore pipelines are equally as sophisticated and expensive as offshore drilling equipment.

Drilling equipment is the same. Whether drilling on land or offshore, the basic equipment used to make hole is virtually the same. Special equipment has been developed to handle conditions that are



Construction recap

Rig type	Net additions, last 12 months	Today's fleet	For completion, next 12 months	Available for 1983
Jack ups	80	358	86	444
Submersibles	6	28	6	34
Semisubmersible	9	120	23	143
Drillships	(3)	58	6	64
Drill barges	4	28	7	35
TOTAL	96	592	128	720

Fig. 1–3 Offshore rig types. (courtesy Oil & Gas Journal, ref. 8*)*

peculiar to some types of offshore drilling, such as tools to compensate for the constant motion of a floating drilling vessel. These are designed to keep the bit in constant contact with the rock at the bottom of the hole during the up-and-down motion of the rig. Other equipment has been developed to make the handling of pipe safer on floating rigs.

Aside from these modifications for the special conditions encountered in a marine environment, the hole is still drilled the same way as a hole would be drilled on land. The rotary rig, which is mounted on the drilling vessel, has the same basic equipment as a land rig—rotary table, drawworks, mud pumps, mast. And the rig's function is the same: To rotate the bit in constant contact with the rock at the bottom of the hole and to remove rock cuttings by circulating drilling fluid down through the drill pipe and back to the surface.

The difference is that in offshore drilling this conventional rig and its equipment must be supported on a marine vessel that usually costs many times more than the rig itself. And supply and service for the drilling operation is complicated by the marine environment.

In addition to land and offshore, there are many other ways to classify wells—exploration vs. development, for example—but the same basic type of drilling rig is used to drill most wells. Its size may vary; its support may differ, as in the case of offshore drilling; and it may have special auxiliary equipment for a special job. The basic components, however, are the same, regardless of the type of well being drilled or its location.

Technology for all environments

Today's search for oil and gas has taken the drilling industry into the world's most remote areas. Wells have been drilled under a wide range of environmental conditions, including the most hostile in the world.

In addition to drilling in water depths of several thousand feet, offshore wells have been drilled in seas where maximum wave heights can reach 90 ft and where storms are among the most severe ever encountered. Offshore wells have been drilled in Arctic waters from man-made islands (Fig. 1–4) by deviating the well from the vertical under controlled conditions. In some areas, wells have been drilled from floating drilling units while constant watch was maintained for moving icebergs. Plans for abandoning the well or taking other steps as an iceberg nears the rig are laid out before the rig is ever placed on location.

On land, wells are drilled in the world's large deserts where no roads exist. The rig must be moved to location on special carriers. Supply and crew transportation is often only by air. Rigs have also been specially

designed to be carried in modules by helicopters and landed in jungle areas. In some cases, bulldozers must be disassembled, flown by helicopter to these locations, and reassembled before a drilling site can be cleared. Other difficult conditions for drilling are caused by natural or man-made obstacles, and it is necessary to drill directionally—slant the hole—because the rig cannot be erected where desired.

All of this experience has shown that a well can be drilled virtually anywhere a commercial deposit of oil or gas is suspected. It may be difficult and enormously expensive, but the drilling industry has the know-how and the personnel to do it.

Types of wells

Although the equipment used to drill most oil and gas wells is quite similar, there are a number of different types of wells, depending on their purpose and their relationship to other wells and fields.

A wildcat well is a well drilled in an unproven area, far from any existing producing well.[11] It is an exploratory well in the truest sense of

Fig. 1–4 Rig drilling on gravel island in Arctic waters.