

OFFSHORE DRILLING AND PRODUCTION EQUIPMENT

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Summary

World consumption of primary energy in 1999 was estimated at 8533.6 million tons oil equivalent. Oil and natural gas accounted for about 65% of the world energy supply.

Offshore areas produced 20-30 % of the oil and gas supply.

Oil and natural gas are brought to the surface from underground reservoirs through wells that have been drilled and completed to produce these fluids safely and economically. Fundamental technology of drilling, completion and production of oil and gas is common to onshore and offshore areas. But environmental conditions of a field affect facilities and engineering works of the field.

This chapter covers the basics of rotary drilling technology, recent progress of drilling engineering, characteristics of various offshore drilling rigs, and types of offshore production systems. The offshore production system adopted to develop a field extends its influence on the drilling and completion method of the field.

1. Introduction

The chapter describes mainly the present situation of offshore drilling and production of oil and natural gas. The first section is devoted for an outline of the rotary drilling method, as oil and gas wells onshore and offshore are drilled by the method.

A hole made by a drilling bit is called a well. The objective of making the well is to produce underground fluids such as fresh water, brine, crude oil, natural gas and geothermal fluids, and to study properties of deeply situated formations.

The Middle East area and China are said to have had wells producing water or natural gas even in the era before Christ. By the year 1200, wells 450 m deep were drilled in China by a spring-pole drilling method. The principle of the method is to generate percussion by dropping heavy tools on the bottom of the hole. The spring-pole drilling method was the predecessor of a cable drilling method that had been used till after 1970s.

Hand-powered rotary devices were introduced to make geothermal wells in Italy and water wells in France in early 1800s. Machine-powered rotary devices and circulation systems were introduced by the late 1850's. In 1901, the Lucas gusher at Spindletop oil field, the United States of America, was successfully drilled and completed by the rotary drilling method with circulation of fluid that consisted of water and clay. The first cementing job to shut off water was carried out in 1903. The use of bentonite as an ingredient of drilling fluid began in 1935 and has contributed to improve mud properties. Three-cutter rock bits equipped with jet nozzles were introduced to clean the bottom-hole of cuttings around 1950.

The technology of directional drilling has made great progress to the level of extended reach drilling (ERD) and horizontal wells through the development of down-hole mud motors and measurement-while-drilling tools (MWD).

Over-water drilling from a pier extended from seashore was carried out in the late 1890's. Drilling and production of oil in the location where the land was out of sight was accomplished offshore Louisiana, the United States of America, in 6 m of water in 1947. The well was drilled from a tender-assisted platform system.

Four basic types of mobile offshore drilling rigs were developed not long after drilling the

first offshore well: the submersible rig in 1949, the ship-shaped rig in 1953, the jack-up rig in 1954, and the semisubmersible rig in 1962. Drill ships and semisubmersible rigs are called floaters. These structures float during operations. Floaters are equipped with unique facilities that are not used in onshore operations: the marine riser, the motion compensation, and the stationkeeping system. The dynamic positioning system (DPS) was introduced for deep-sea operations in 1961.

The scientific research well “SG-3” in Russia reached the depth of 12 263 m in 1988, and has had the depth record ever since. The deepest exploration drilling for hydrocarbons was carried out to the depth of 9583 m in the United States of America in 1974. As for offshore wells, a hydrocarbon exploration well was drilled offshore Brazil in 2965 m of water in 2001. A production well was completed with a subsea completion system offshore Brazil in 1852 m of water in 1998. The offshore technology is steadily in progress toward deeper and deeper seas to search and produce subsea resources for the future welfare of the world.

2. Outline of Rotary Drilling Method

The rotary drilling method is usually applied to make deep wells. In the rotary drilling a bit breaks down rocks at the bottom of the hole by scraping and crushing actions. The bit is rotated through a drill stem by a rotary table on a rig floor.

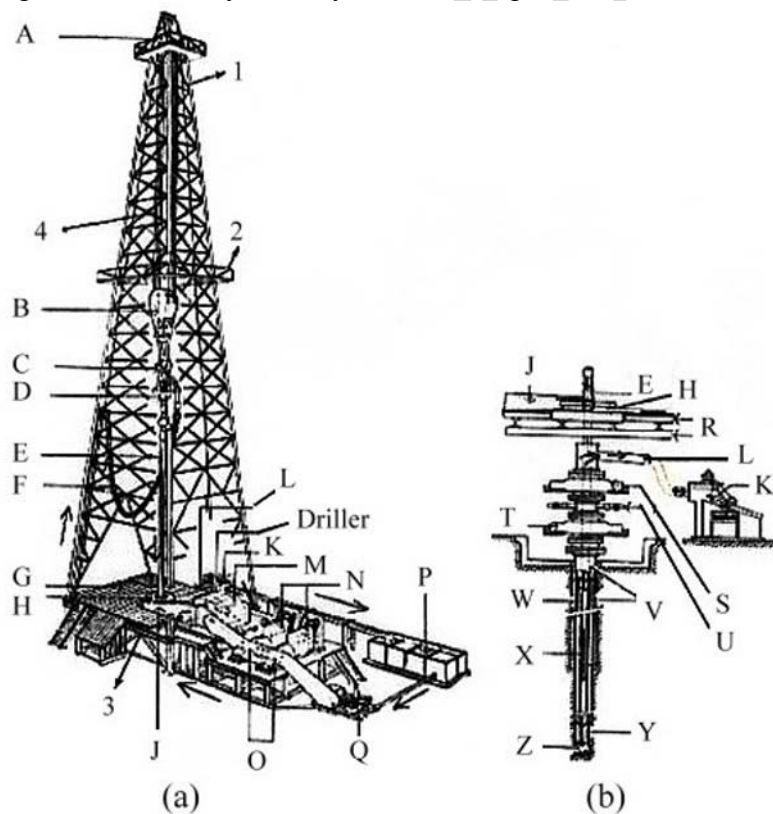


Figure 1: Diagrammatic View of Rotary Drilling Rig
(Modified from Rabia H. (1985). *Oilwell Drilling Engineering, Principles and Practice*, Graham & Trotman)

A diagrammatic view of the rotary drilling rig is shown in Figure 1. The left side of the figure shows main surface equipment. The substructure indicated by 3 is constructed on the ground as the foundation to support the derrick floor G on which the derrick 1, rotary table H, and drawworks M are placed. The monkey board (or platform) 2 is a working floor to handle pipes. The heavy materials such as the drill stem and casing are lowered into or lifted up from the hole by a hoisting system composed of the drawworks M, drilling line 4, crown block A, traveling block B, and the hook C.

A circulation system of drilling fluid consists of the suction pits P, pumps Q, surface piping, standpipe, rotary hose (or kelly hose) F, and swivel D which is connected to the kelly E, and directed lines show the flow path of the drilling fluid.

In the figure main power sources are the diesel engines N, and the power is transmitted to the rotary table, drawworks and pumps by the main transmission system O. The rotary table is driven by the drive J. Sometimes electric motors are used to drive the relevant machines. A driller controls the machines from the console by the drawworks and conducts the drilling operations.

In the right side of the Figure 1 showing the cross-section of the derrick floor R and the hole, blowout preventers (BOPs) S and T are mounted on the top of the wellhead connected to the surface casing V. It is the primary function of the BOPs to safely confine fluids suddenly entering into the hole out of formations, and to bleed them off from the hole through the outlets U in a controlled manner.

The drill stem is composed of the kelly E, the drill pipe X, and drill collars Y. The bit Z is attached at the lower end of the drill collars. The components of the drill stem are made of steel pipes. The drilling fluid is circulated down to the bit through the drill stem, and up to the surface through the annular space between the drill stem and the borehole or casing. The drilling fluid returned to the surface flows into the return line L, and then to the shale shaker K to separate cuttings and fluid. The fluid falls into the suction pit P to be circulated again

The casing consists of lengths of steel pipe being joined to another. A number of strings of casing are set in the well. The purposes of casing are to protect fresh-water sands, to prevent drilling problems such as heaving formations and high-pressure zones, and finally to provide a means of production of oil and gas if the well is productive. The annular space between the casing and the borehole should be filled with cement W to support the casing and prevent the flow of underground fluids up to the surface and/or into the fresh-water zones. Conductor casing is the largest-diameter casing used to protect the surface soils. The next smaller-diameter casing is the surface casing V. Its main function is to protect fresh-water zones. Intermediate strings of casing are set to case the long open section of the hole or the zones causing trouble. The last string of casing is the production casing that is set immediately above, or through, the production formations

The main functions of the rotary drilling rig are as follows:

- (a) Penetrating operations. The bit breaks down rock at the bottom-hole by the rotation under the weight. The rotating force of the rotary table is transmitted

through the drill stem to the bit. Some portion of the weight of drill collars is applied to the bit as the bit weight to push the bit against the rock.

- (b) Hoisting operations. The drill stem with the bit is lowered and lifted by the hoisting system. The casing is also handled by the hoisting system.
- (c) Conditioning and circulating the drilling fluids by the circulation system.
- (d) Preventing the formation fluids from entering into the wellbore and controlling them.

The International Association of Drilling Contractors (IADC) classifies the bits used in the rotary drilling as follows:

- (a) Roller bits (or roller-cone bits).
 - Steel tooth bits.
 - Insert bits (or tungsten carbide insert bits).
- (b) Fixed cutter drill bits.
 - PDC bits (PDC: polycrystalline diamond compacts)
 - TSP bits (TSP: thermally stable polycrystalline)
 - Natural diamond bits

Three types of bits are shown in Figure 2.

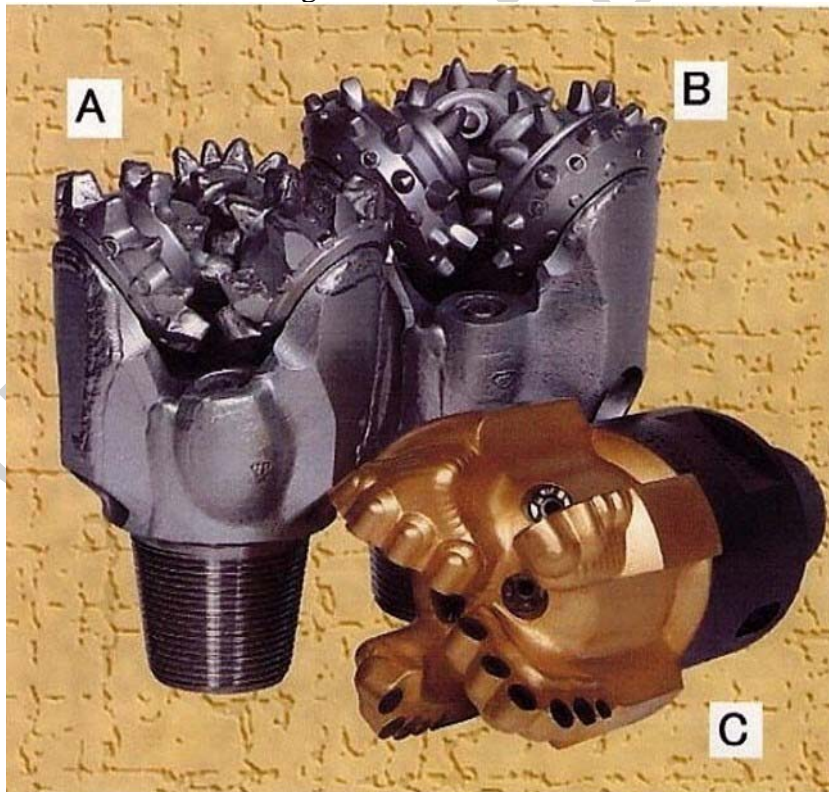


Figure 2: Three Types of Bits Used in Rotary Drilling
A: steel tooth bit, B: insert bit, and C: fishtail PDC bit.
(From *Drill Bit Catalog* © 1995 – Hughes Christensen
Reproduced Courtesy of Hughes Christensen Company)

The IADC bit classification system provides conventional methods for categorizing roller bits by three digits, and fixed cutter drill bits by four characters. The choice of bits depends upon properties of the formations, and drilling techniques (see *Drilling Machines*).

The drilling fluids, conventionally simply called as muds, have lots of important functions in the rotary drilling. Main functions are as follows:

- (a) Removal of cuttings from the bottom of the hole to the surface. Cuttings are separated from the mud at the shale shaker. These cuttings and samples of the mud are analyzed to study geological properties of the rocks penetrated, and to find out the indication of oil and gas in the formations.
- (b) Controlling hydraulic pressure in the hole by adjusting the density of the mud to prevent collapse of the wall of the borehole, and to contain formation fluids in the formations.
- (c) Cooling and lubricating the bit and the drill stem.

The drilling fluids are composed of base fluids, clay minerals, chemicals, and inert solids. Their base fluids classify them as follows: water-base muds, oil-base muds, air or gas drilling. Bentonite, a kind of clay, is preferred to make up water-base muds. A small quantity of chemicals adds in the mud to control the viscosity and filtration properties. Inert solids such as barite are mixed in the mud to adjust the density.

In the conventional system of the rotary drilling, the rotary table rotates the drill stem, but the down-hole mud motor and the top drive device are applied to rotate the bit in the directional and horizontal well drilling, or to improve operations in the vertical well drilling. The technical advancement of the measurement-while-drilling tools (MWD) and the logging-while-drilling tools (LWD) has contributed to the almost real-time acquisition of the down-hole information. Owing to these tools it has become easy to drill directional and horizontal wells.

Directional wells with long horizontal departure are called extended-reach-drilling (ERD) wells. The definition of an extended reach well is a well with a measured depth to true vertical depth ratio greater than 2.0. An ERD well in the United Kingdom drilled in 1999 to access offshore reserves from onshore had a record of a departure of 10 728 m with a measured depth of 11 287 m and approximately 1600 m true vertical depth. A definition of a horizontal well is a well with a hole section exceeding an inclination of 85 degrees.

The adoption of the directional wells, extended-reach wells, horizontal wells, and the multilateral wells has a share in the economical development of oil and gas fields. Figure 3 is an example of horizontal wells in the North Sea. Figure 4 shows various types of multilateral wells.

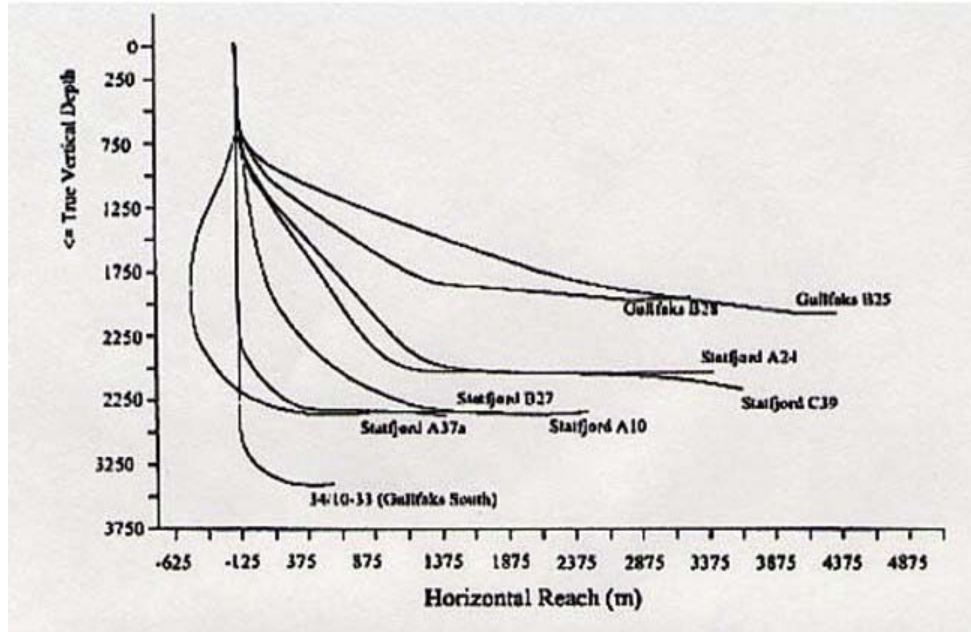


Figure 3: Examples of Horizontal Wells in the North Sea
 (From Blikra H., Drevdal K.E., & Aarrestad T.V. (1994). *Extended Reach, Horizontal and Complex Design Wells: Challenges, Achievements and Cost-benefits, Vol.2, Exploration, Production, and Reserves, Proc. of the 14th World Petroleum Congress, John Wiley & Sons.*)

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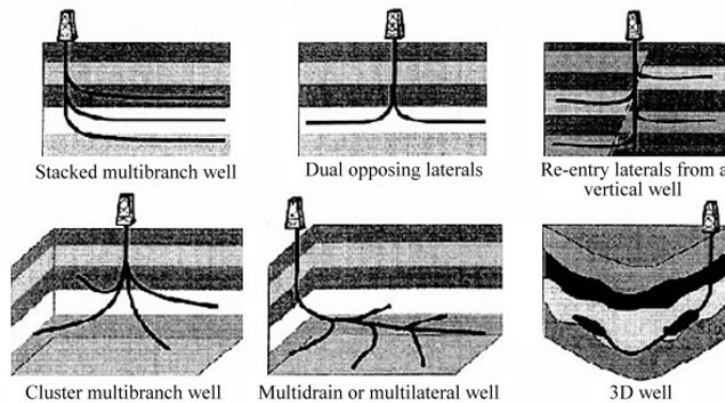


Figure 4: Various Types of Advanced Wells

(From Renard G., & Delamaide E. (1998). *Complex Well Architecture, IOR and Heavy Oils,*

Vol. Production, Proc. of the 15th World Petroleum Congress, John Wiley & Sons.)

Reproduced Courtesy of World Petroleum Congress)

There are two basic types of down-hole mud motors; one is a turbine type (turbo-drill), and the other is a positive displacement type (PDM). Figure 5 is an illustration of a multi-lobe (5/6) rotor/stator configuration type of the positive displacement motor. The motor is designed primarily for the directional performance drilling motor, but can also be used for

straight-hole drilling.

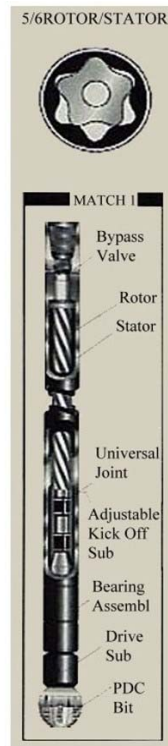


Figure 5: Diagram of Multi-Lobe Mud Motor
 (From the General catalog, Eastman Christensen™
 Reproduced Courtesy of Baker Hughes INTEQ)

The top drive drilling system is suspended from the swivel, moves up and down together with it, and rotates directly the drill stem by electric or hydraulic motors.

In the MWD and LWD systems, sensors are set within the drill collars just above the bit. In the MWD, the hole direction and inclination are measured, and the downhole weight and torque on the bit are included in a modified type of the tool. In the LWD, the formation resistivity and natural gamma ray are measured. The term MWD is often used as a synonym for the term LWD. Data measured at the downhole are transmitted to the surface in a real-time mode by coded mud pulses sending up inside of the drill stem or the annular space. Some sophisticated data transmission systems consist of electromagnetic wave propagation through the earth, or sonic wave propagation through the drill stem. Figure 6 is an illustration of a positive mud pulse system of the MWD system.

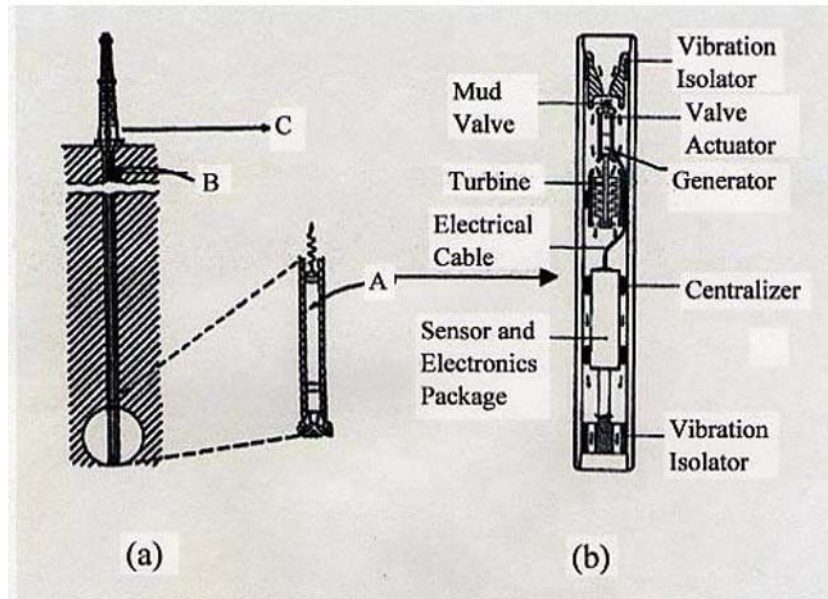


Figure 6: Positive Mud Pulse System of MWD
 (Modified from Busking B.E. (1979). *Developments in Drilling Technology*,
 Vol. 3, Production, Proc. of 10th World Petroleum Congress, Heyden & Son Ltd.
 Reproduced Courtesy of World Petroleum Congress)

In the right side of Figure 6, a MWD tool A is enlarged. In the left side of the Figure 6, positive mud pulses B move up through the drill stem to a pressure detector C at the surface. In the MWD tool measured data are converted into binary signals by an electronics package. The binary data control movement of a valve actuator to produce positive pulses of the mud in the drill stem.

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Bibliography

Bourgoyne Jr. A.T., Millheim K.K., Chenevert M.E. and Young Jr. F.S. (1991). *Applied Drilling Engineering*. Richardson, TX 75083-3836, USA: Society of Petroleum Engineers. [This is a good textbook on rotary drilling engineering.]

Gerwick, Jr. B.C. (1986). *Construction of Offshore Structures*. Baffins Lane, Chichester, Sussex PO19 1UD, UK: John Wiley & Sons. [This book gives details of how offshore structures, particularly the bottom-supported platforms, are constructed.]

Silcox W.H., Bodine J.A., Burns G.E., Reeds C.B., Wilson D.L. and Sauve E.R. (1989). Chapter 18 Offshore Operations. *Petroleum Engineering Handbook* (editor-in-chief H.B. Bladley), pp. 18-1 – 18-52. Richardson, TX 75083-3836, USA: Society of Petroleum Engineers. [This work provides a good overview of offshore drilling and production systems and operations.]

API Standards and Publications. 1220 L Street, Northwest Washington, D.C. 20005-4070, USA. American Petroleum Institute. [The series contain detail standards and information on rotary drilling method of onland and offshore operations.]

OTC Proceedings. Richardson, TX 75083-3836, USA. Society of Petroleum Engineers. [The proceedings published yearly provide up-to-date information on offshore engineering and operations.]

Proceedings of SPE/IADC Drilling Conference. Richardson, TX 75083-3836, USA. Society of Petroleum Engineers. [The proceedings published yearly provide up-to-date information on drilling engineering.]

Biographical Sketches

Shoichi Tanaka is professor emeritus of the University of Tokyo in Tokyo, Japan. He majors in drilling engineering and petroleum engineering. He holds a Doctor of Engineering in mining engineering from the University of Tokyo. He was with the University of Tokyo from 1960 to 1995.

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Yuichiro Ichikawa is currently working concurrently as general manager of Methane Hydrate Development Division of Tokyo head office of Japan Drilling Co. (JDC). He is responsible for drilling operations, drilling engineering and offshore engineering services to the drilling industry and governmental bodies. He joined JDC in 1977 and has worked in numerous projects in varying capacities since then. Areas of engineering expertise - Deepwater Drilling Rig Design, Deepwater Location Surveys, Deepwater Well Planning, Deepwater Subsea Well Control, Coring Technology, Downhole Tools Development, Hydrate Drilling, Safety Management, Information Management, Logistics Support and Deepwater Offshore Drilling. He holds a BSc in petroleum engineering from the University of Tokyo.