DRILLING ENGINEERING

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Summary

The term “drilling” related to a well indicates the sequence of operations, tools and materials required to construct a circular borehole in the subsoil for geological exploration purposes or for the production of underground fluids such as hydrocarbons, groundwater, geothermal fluids, etc. A well is drilled by applying technologies not requiring direct access by man at the bottom of the borehole. Any drilling technology is based on the application of the following basic actions: a) overcoming the resistance of the rock at the bottom hole, crushing it into millimeter or sub-millimeter particles (cuttings); b) removing the cuttings from the bottom hole; c) ensuring the mechanical stability of the borehole walls; d) preventing the underground fluids contained in the drilled formations from entering the well.

The above actions can be achieved by various drilling technologies, developed throughout the last two centuries. However, this study illustrates the principles of rotary drilling, so far the most developed technology and the only one utilized in the field of oil and gas exploration and production. In particular, this chapter illustrates the operations, tools and materials employed in rotary drilling rigs utilized on shore. The drilling rigs used on shore are modular equipment which can be moved from a drill site to another in a reasonable short time, from a few days to weeks (Figure 1). Offshore drilling follows the same basic principles, tools and materials deployed on shore, but they are configured with a number of different drilling systems to suit operations in the marine environment. Normally these rigs are self contained aboard of a floating vessel. For more details about offshore drilling see "*Offshore Drilling and Production*".

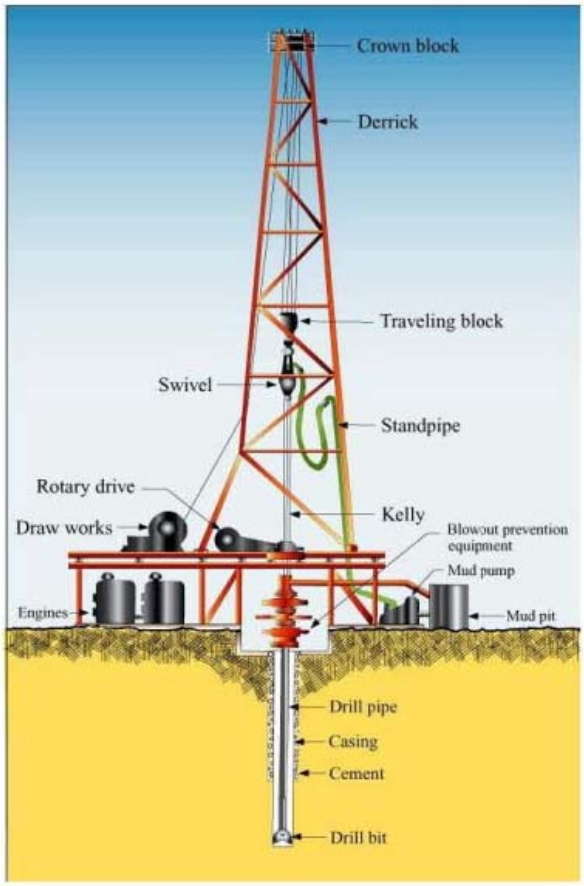

Figure 1. Typical drilling rig utilized in rotary drilling.
(Image from State of California, Dept. of conservation, www.consrv.ca.gov/, public domain)

1. Introduction

In rotary drilling the hole is bored using a drill bit, which is pushed and rotated against the rock at the bottom of the hole by a rotating drill-string of steel pipes. The cuttings produced by the bit are continuously circulated up to the surface by a drilling fluid

(liquid, gas or foam), pumped inside the drill-string down to the bit and back up to the surface. After having drilled a certain length of borehole, a steel pipe (or casing) is run in the hole to prevent the mechanical collapse of the open borehole. The space between the casing and the borehole is sealed with cement slurry to ensure mechanical stability and hydraulic insulation. The final depth of the well is thus accomplished by drilling a sequence of cased boreholes of decreasing diameter, producing a structure made up of concentric tubular elements.

The drilling rig consists of a set of equipment and machinery positioned on a restricted area called drilling site, normally occupying from 1 to $2 \cdot 10^4$ m^2. Normally the rig is not owned by the oil company but by drilling service companies, which hire out the rig and which construct the well according to the client's specifications. The most important items of equipment of a rig for oil and gas drilling are depicted in Figure 2.

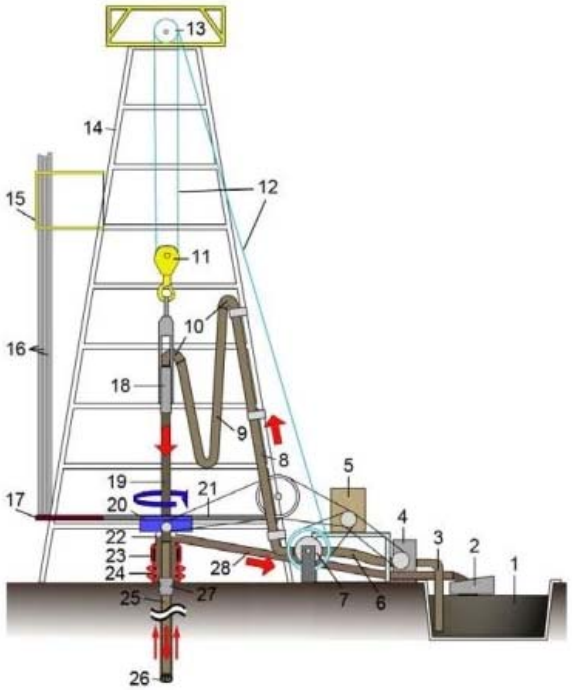

Figure 2. Components of a drilling rig. 1) Mud tank. 2) Shale shakers. 3) Suction line. 4) Mud pump. 5) Motor or power source. 6) Surface manifold. 7) Draw-works. 8) Standpipe. 9) Kelly hose. 10) Goose-neck. 11) Traveling block. 12) Drill line. 13) Crown block. 14) Derrick. 15) Monkey board. 16 Stand of drill pipes. 17) Pipe rack (floor). 18) Swivel (On newer rigs this may be replaced by a top drive). 19) Kelly drive. 20) Rotary table. 21) Drill floor. 22) Bell nipple. 23) Blowout preventer, Annular type. 24) Blowout preventer, ram type. 25) Drill string. 26) Drill bit. 27) Casing head or Wellhead. 28) Flow line.
(Image from *Wikimedia Commons*, public domain)

In rotary drilling, the drill-string (and hence the drill bit) is rotated either by a rotary table (the classic device), a top drive or a downhole mud motor, and is pushed against

the bottom hole by the weight of the drill-string itself. The drill-string is connected to a swivel hanging to the hook, controlled and operated by a hoist and a derrick. The swivel serves to let the drilling fluid pass from the surface hydraulic circuit to the interior of the pipes. The drill-string is operated with a hoisting system (normally a block and tackle system) operated by a wire rope (drilling line) and a hoist (drawworks). The crown block is located at the top of the derrick. The function of the derrick is to support the crown block, and it is tall enough to handle the drill string in the hole.

The drilling fluid circulates in a closed circuit: it flows through the inner bore of the drill-string and the bit, removes the cuttings from the bottom hole, and then rises through the annular space between the drill string and the hole. Once at surface, the drilling fluid is conveyed onto the shale shaker, which separates the cuttings from the fluid. The fluid is then conveyed to the mud pumps which circulate it to the swivel via a surface manifold, closing the circuit. Circulation of a drilling fluid, also known as mud, is the distinctive element of rotary drilling, as it permits the continuous removal of the cuttings from the bottom hole.

As the well is drilled deeper and deeper, new drill pipes must be connected to the drill-string, and the drill bit must be replaced as soon as it looses its drilling efficiency due to excessive wear. In this case, the whole drill-string must be tripped out of the hole, the bit replaced, and the drill-string must be tripped in the hole again. This operation is called roundtrip: at depths of 3000 m, a roundtrip takes approximately 7 hours, which increases to 12 hours at a depth of 4000 m. These are rather lengthy times when it is considered that the average life on bottom of a bit at such depths is about 50 to 100 drilling hours, and that the hire cost (or rig rate) of a large onshore drilling rig is in the range of 25 000 euro/day, while for offshore rigs it can exceed 200 000 euro/day.

Nowadays, the industry of hydrocarbon exploration and production has established safe and sound technologies to drill wells also at considerable depth and in marine environment. In the last few decades the solution of considerable technical problems has led to important progress in the understanding of drilling problems, in the knowledge of rock stability at great depths, and in the formulation of sophisticated and environmentally friendly drilling fluids.

2. Drilling Rigs

A drilling rig is a compound of several equipments and tools assembled with the purpose of creating boreholes in the ground. Drilling rigs used in the oilfield are massive structures housing equipment to drill wells whose depth, in a few cases, has even exceeded 10 km. Drilling rigs are mobile equipment mounted on trucks, tracks or trailers; in some cases, they are more permanent land or marine-based structures (such as offshore rigs). Therefore, the term drilling rig refers to the complex of equipment that is used to drill boreholes in the subsoil.

Drilling rigs can be either small (or portable, such as those used in mineral exploration drilling, water wells and environmental investigations), or large, *i.e.*, those capable of drilling deep wells for hydrocarbon exploration. In this case, if the rig is utilized in remote locations, it is equipped with permanent living accommodation and catering for

crews (which may be more than a hundred). Marine rigs may operate many hundreds of km offshore with infrequent crew rotation.

Drilling rig is constructed in type, size and capacity according to the purposes and the characteristics of the hole to be drilled. The simplest criterion for the classification of a drilling rig is based both on the "capacity", *i.e.* the drilling depth that can be attained, and on the power used on the rig itself, which for oil well drilling is in the range of at least 10 HP every 100 feet in depth (approximately 250 W/m). Normally, drilling rigs are classified into four groups: 1) Drilling depth to about 2000 m, 650 HP installed (478 kW). 2) Drilling depth to about 4000 m, 1300 HP installed (956 kW). 3) Drilling depth to about 6000 m, 2000 HP installed (1.47 MW). 4) Drilling depth more than 6000 m, 3000 HP installed (2.2 MW), or more. Other classifications can be made taking into account the power used, the derrick height, the pipe used, the method of pipe rotation, *etc*.

The drilling rig is set up on a leveled area, called the drilling site, which contains the derrick, the service equipment, the mud system, the power units and the crew quarters. In onshore oil and gas exploration the drilling site is a surface area of about 10 000 to 20 000 m^2, utilized from just a few weeks to more than a year (in the case of exploratory wells in difficult situations), which is eventually dismantled and environmentally restored at the end of drilling operations. If the well is dry, the area is handed back to its owner. If the well is productive, the wellhead is permanently fenced into a smaller area in the range of about 100 m^2 or less.

During drilling, the representative of the Oil Company (known as the drilling assistant) controls the drilling operations and co-organizes the safety on site. Service companies (or Contractors) also operate on site to carry out specialized jobs (cementing, logging, geological assistance, *etc*.). Drilling operations are performed by the drilling crew, whose numbers vary from rig to rig. Normally, there is a foreman (rig supervisor), in charge of the drilling rig, a driller, a derrickman, two-to-three drill assistants, a roustabout, maintenance hands (electrician and mechanic) and one or more watchmen. The driller controls all drilling equipment and carries out the sequence of operations to drill the hole. The derrickman operates on a platform inside the derrick and handles the pipes during roundtrips. The drill assistants, headed by the driller, handle the drill string connections during drilling and tripping operations and other operations on the drill floor. All rig site personnel work in day shifts, since drilling is uninterrupted, except for the technical stops necessary for particular operations.

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Biographical Sketch

Paolo Macini is Associate Professor of Petroleum Engineering at the University of Bologna (Italy). Prof. Macini holds a M.S. Degree in Mining and Petroleum Engineering from the University of Bologna. He is a Registered Professional Engineer in Italy. Before joining the University, he worked for a Service Company supplying tools and services to the oil and gas industry, with experiences in Italy, North Sea, Africa and USA. He joined the University of Bologna in 1992, and his present appointment is Associate Professor at the Civil, Environmental and Materials Engineering Department. Prof. Macini has taught a number of classes at the University of Bologna. Principal among them are Underground Fluid Mechanics, Drilling Engineering, Reservoir Engineering and Petroleum Production, which are also the main areas of his research activity. He has authored or co-authored more than 100 papers and three books. Prof. Macini is a member of the Society of Petroleum Engineers (SPE), where he served for more than 10 years in the Board of the Italian Section and as Chairman of the Ravenna Subsection, of the American Society of Mechanical Engineers (ASME), of the Russian Academy of Natural Sciences (US Section) and of the Italian Society of Mining Engineers (ANIM).