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Continuous Circulation System: A Key to drilling safety increment

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Abstract

During drilling operations, it is clear which a noticeable amount of costs is spent on drilling problems; such as lost circulation, stuck pipe, and excessive mud cost. In addition decrement the percentage of non-productive time (NPT) caused by these kind of problems, the purpose is to introduce Continuous Circulation System (CCS) that was first informed with commercial successes offshore in Egypt and Norway. Currently managed pressure drilling (MPD) has ease it to drill reservoirs that has a narrow window between pore and fracture pressure gradients. Circulating the mud pumps off and on for connections affects the pressure and it is a main problem for MPD’s safety. This paper illustrates how was CCS developed in drilling industry and reduced the problems of health and safety at work. Due to these expressions, it shows advantages in compare with MPD. Then its applications has investigated and compared the performance of various companies, which are used CCS method on various rigs. Eventually, capability of continuous circulation system in Iran is checked to appreciate how CCS can improve drilling safety’s industry in west Asia. Currently, down hole oil-water separation (DOWS) technology, as a technique of separating water downhole to reduce surface water production has been developed. This technique let water to be separated in the wellbore and injected into a suitable downhole zone while oil is produced to the surface. One of the major reasons of water coning in oil well is the pressure drop caused by the oil production in oil zone which invariably limits the ultimate oil recovery. If an equal pressure drop in the aquifer is used, water will not rise up and water coning can be controlled, then the drained water can either be lifted to the surface or be injected into the same aquifer at a deeper depth. This article investigates the diverse approaches of controlling coning of unwanted fluid in the wellbore within optimizing oil production from the reservoir.

Keywords: Drilling, safety, Circulation System, ECD, MPD

1. Introduction

In the oil and gas industry a new technology known as Managed Pressure Drilling (MPD) is emerging, allowing for faster and more accurate well pressure control. MPD differs from conventional drilling methods by closing the well using a controlled choke, often in combination with a back-pressure pump allowing for automatic pressure control. When the drill string is extended the pipe is typically sealed off and detached from the MPD system. This process is time consuming and limits pressure control, because the mud flow is stopped. Cycling the mud pumps off and on for connections affects the pressure and it is a major problem for MPD Fig. 1 shows the pressure spikes that occur when making a connection. When the pumps stop, the pressure in the well decreases. This decrease in pressure can cause a kick, formation fluids enter the wellbore. The formation could also relax and the formation could collapse on the hole, resulting in stuck pipe. The differential pressure between the reservoir and the wellbore can also stick the pipe. The drilling fluid starts to form a gel when the pumps are turned off as the fluids stop circulating. When the pumps are restarted, pressure increases to break the gel, causing a pressure spike which could cause lost circulation, where fluids enter the formation, and ballooning of the wellbore. Before a connection is made, the rig has downtime associated with circulating the cuttings out of the bottom-hole assembly. This is required so that the cuttings do not settle at the bottom-hole assembly. No one single technique (MPD) will enable have the best performance to be drilled a well from surface (or mud line) to total depth (TD) in one go. So multiple complementary innovations are required. The desired goal is to introduce a new technology with Special Characteristics which, the ultimate in well-construction efficiency from spud through completion. With a continuous circulation system in place, steady-state conditions can be maintained downhole so that formations do not suffer pressure oscillations. Well cleaning is improved, and the ability to pump out of hole for extended intervals allows to reduce the chance of problems in the open hole section until the bit is inside the previous casing (Fig1). During connection, the drill pipe is suspended from a pressurized chamber that comprises two pipe rams and one blind ram. This arrangement enables the circulation of mud down the drill string to be maintained throughout the entire section the Continuous Circulation System is developing to allow for better pressure control during connections and reducing connection time. Existing technology for drilling with circulation is confined to coiled tubing with its inherent constraints on hole size and inability to rotate the drill-string. At some stage, circulation must be interrupted to introduce an additional coil as the hole is deepened. The CCS allows the drilling of the full range of hole sizes and the penetration of a complete hole section without stop- ping circulation and the pumps can be left running, maintaining circulation while adding or removing a stand or joint of drill pipe to or from the drill-string. Uninterrupted circulation allows the established circulating pressure regime, Considered under the (CBHP) variation as well, Hannegan stated that Continuous Circulation Systems technique keeps the ECD constant by not interrupting circulation during drilling operations, to be maintained and eliminates the problems caused by the loss of the dynamic circulating pressure component when the pumps are stopped. It also eliminates the positive and negative pressure stresses to the wellbore, induced by stopping and starting circulation when making connections conventionally. The method is used on wells where the annular friction pressure needs to be constant and/or to prevent cuttings settling in extended reach horizontal sections of the wellbore. The circulation can be maintained during connections or other interruptions to drilling progress by using a special circulating BOP system or via continuous circulating subs being added to the drill string [1].

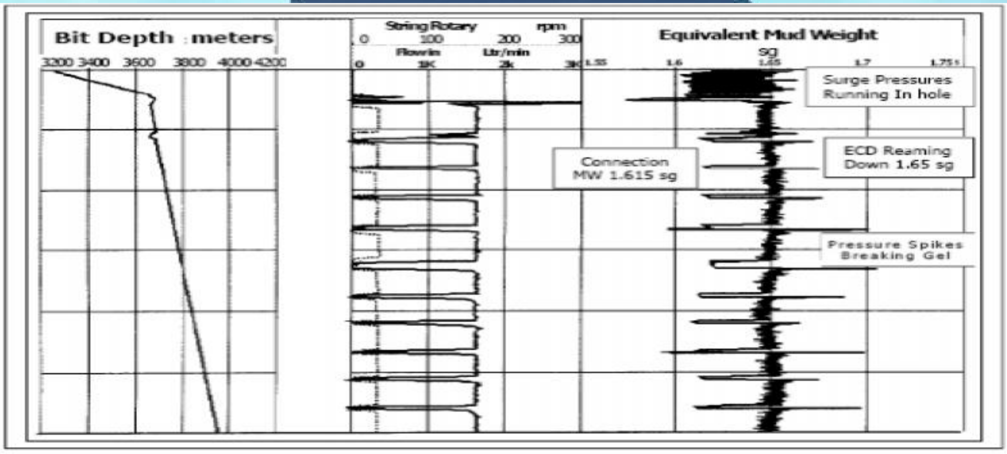

Fig.1: Change in equivalent mud weight during connections.

2. CCS Advantages

2.1 Maintains constant mud flow and cuttings mobility

- Provides an even distribution of cuttings throughout the annulus
- Reduces cuttings bed formation in lateral and ERD wells
- Reduces the likelihood of a stuck bit or BHA
- Maintains an even temperature throughout the annulus
- Provides a steady loading of the mud cleaning equipment
- Eliminates circulation time before making connections
- Eliminates re-drilling of settled cuttings & debris after making connections
- Eliminates need to circulate out accumulated gas after connections in UBD wells. [2]

2.2. Increase Safety

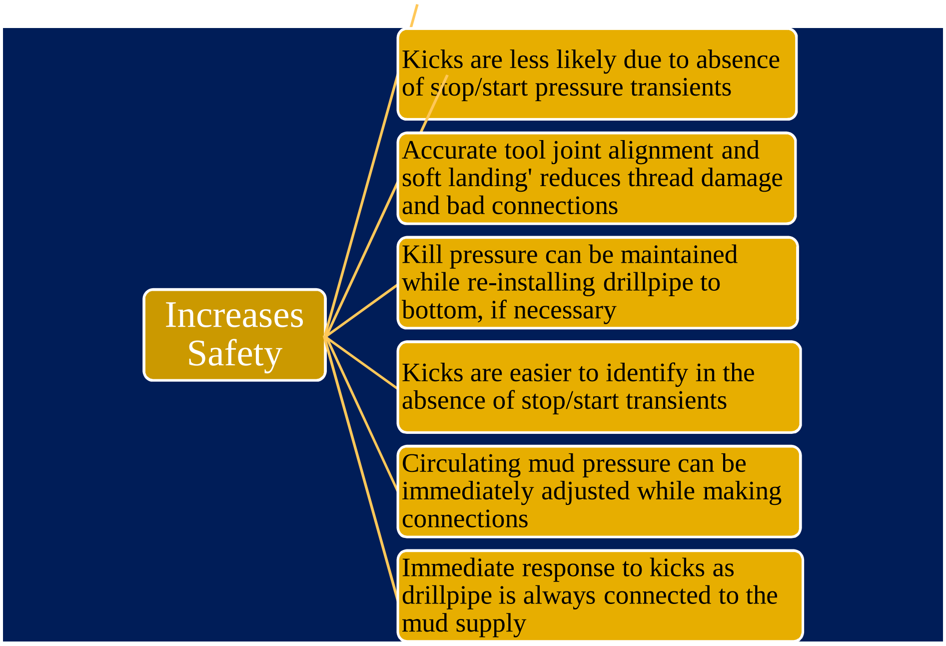

Fig.2: Some operations in CCS which are increasing Safety

2.3. Other preponderance:

- such as Only one modification to the rig is required to install the system, No need even one changes or additions to the drill-string and at the end The connection process is “hands off’.

3. Application

CCS has been particularly effective when used to drill formations where making connections conventionally is difficult due to narrow drilling window. Balanced pressure drilling is unique among managed pressure drilling techniques. It maintains uninterrupted circulation during connections to establish constant BHP regime throughout drilling. This steady-state circulating condition eliminates the transitory down-hole pressure effects experienced during conventional drill-pipe connections. Using CCS can result in improved hole-conditions and may reduce connection time. Depending on the situation and professionalism of CCS crew may reduce connection time.

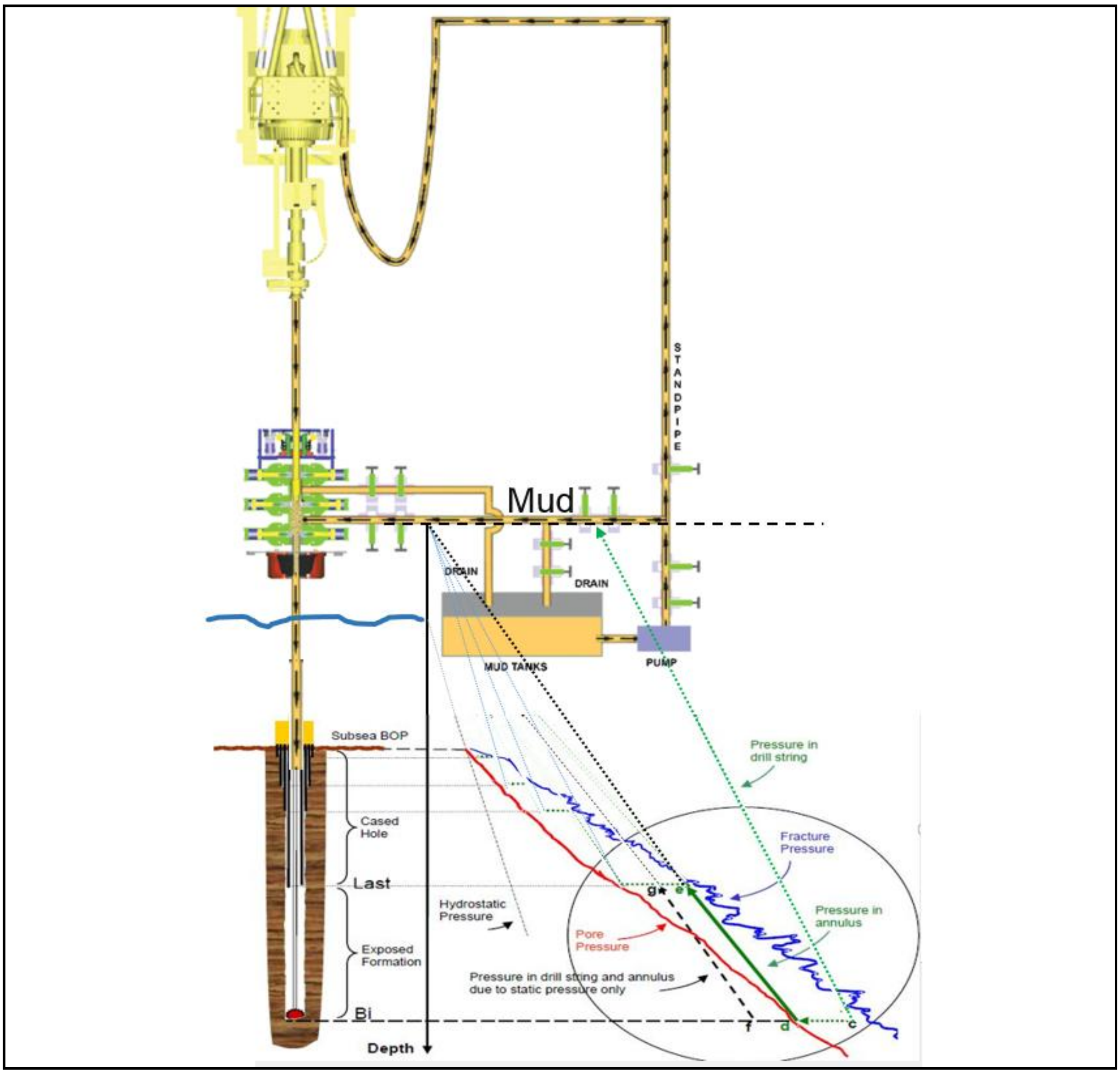

Fig.3: Stable Pressure Gradient across the Exposed Formation When Drilling with CCS

4. Invention and development of CCS

The first in a series of worldwide patents was applied for CCS in October 1995. As it is cited in the Rasmussen and Sangesland’s study, the system was developed by a (JIP) managed by Maris

International which was supported by six major European oil companies; BG, BP, Eni SPA, Shell UK, Statoil and Total, supported by Varco-Shaffer (now National Oilwell Varco [NOV]) and Coupler Developments Ltd. On completion of the conceptual studies the JIP members gave approval to start work on a prototype system that could handle drill pipe in the range 3-½-in to 5-⅞-in OD at circulating rates of up to 800gal/min at 5000psi [3]. They agreed that 6-⅝-in drill pipe should not be considered as it was obsolescent. This allowed the use of components from 9”x5000psi blow-out preventers (BOP) to be used in the design and construction of the pressure chamber or Main Unit as it is known. Construction of the prototype was enough progressed by December 2002 for initial tests of the system to be manufactured on a research rig in Houston [4]. While circulating at 10 and2400 psi, connections were successfully made using new 5-in XH drill pipe pony joints in a moving and pressurized drilling mud environment. The operation and functioning of the computerized control system was also checked and calibrated. As it is cited in the R.E.Vogel and W.Dunn, study the results were successful as far as people convinced the JIP members to aid continued expansion of the prototype to the stage where it was ready to undergo a full field trial in July/August 2003 on a small land rig drilling for BP America in southern Oklahoma.

5. Structure of Continuous Circulation System

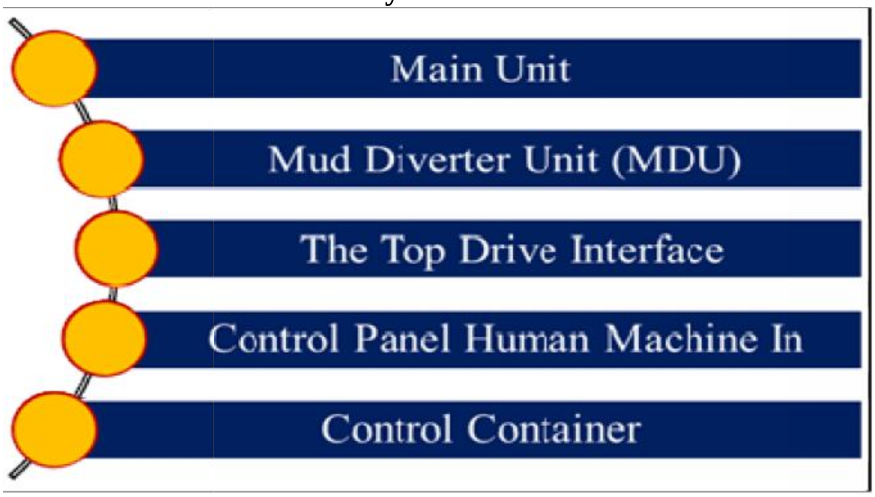

Fig.4: The main structure of CCS

5.1 Main Unit(Pressure Vessel):

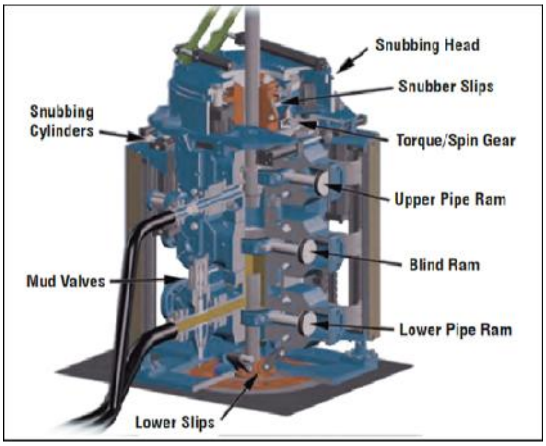

Fig.5: Pressure Vessel (Main Unit)

Main Unit is core of CCS and constructed from three 9-in Bore, 5,000 psi working pressure-rated BOP bodies namely; upper Pipe Ram, Middle Blind Ram and Lower Pipe Ram (is Inverted to contain pressure from above. when in use the Main Unit is located on the rotary table which is the drill string passing through it.) which are located respectively top, center and bottom. A combination make/break Power Tong/Pipe Spinner and Vertical Snubber is attached to the top of the unit by hydraulic jacks. Hydraulically-operated drill pipe slips are attached at the bottom which is used as a landing place for drill string to make break a connection while continuing to circulate, and the pipe rams closed, isolating the tool joint with mud at circulating pressure before filling the cell between the rams. Then the Snubber breaks the connection and allows the pin to rise under control before closing the blind rams. Circulation continues through the open drill pipe box below the blind rams and is closed to the lop Drive, before bleeding off the pressure above the blind rams and opening the upper pipe rams to allow the next stand Joint of pipe to be picked up. The procedure is reversed to make the new connection. As it is cited in the Rasmussen and Sangesland's study, the system was developed by a joint industry project managed by Maris International. During connection, the drill pipe is suspended from a pressurized chamber that comprises two pipe rams and one blind ram. This arrangement enables the circulation of mud down the drill string to be maintained throughout the entire section.

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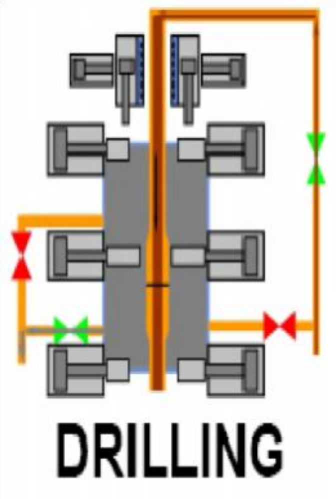
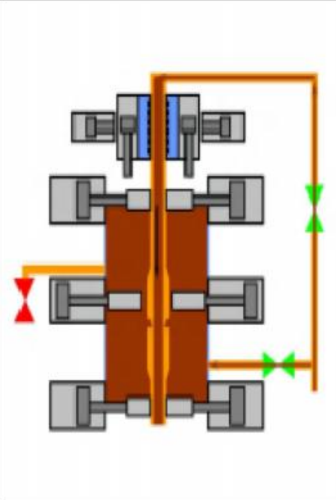
Drilling Start

- Standpipe mud flow open.
- Lower chamber mud drain open.



- Close lower chamber mud flow
- Open lower chamber drain
- Release pressure in chamber
- Release upper and lower pipe rams
- Disengage snubber
- **DRILLING FINISH**

- Close upper and lower pipe rams.
- Engage snubber
- Standpipe mud flow open
- Mud flow into upper and lower chamber and pressurize
- Contain force from mud pressure with snubber
- Break out saver sub



- Close upper chamber drain
- Open standpipe to mud flow
- Open middle blind rams
- Lower drill pipe
- Make connection
- Torque connection with snubber

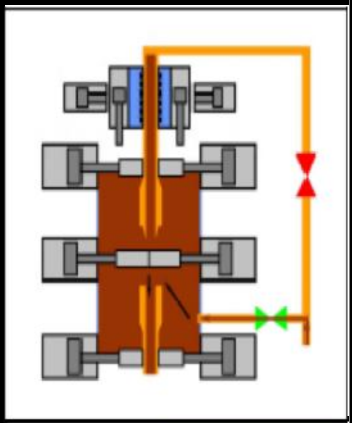
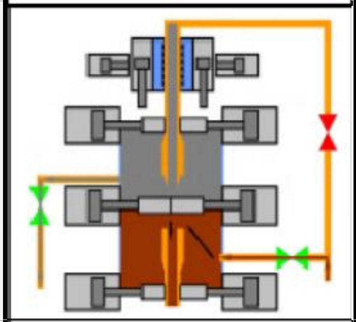
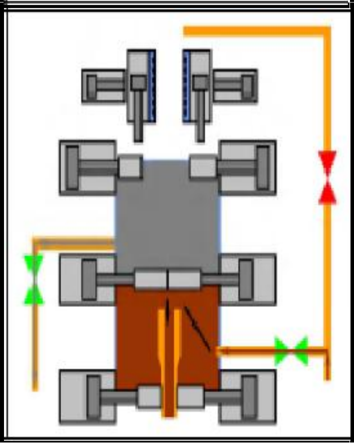
➢ Raise saver sub ➢ close middle blind rams ➢ Mud flow into chamber and pressurize lower chamber Close standpipe mud flow ➢ Mud pumped through drill string via pressurized lower chamber		➢ Mud pumped through drill string via pressurized lower chamber
➢ Mud pumped through drill string via pressurized lower chamber ➢ Depressurize upper chamber ➢ Drain upper chamber		➢ Mud pumped through drill string via pressurized lower chamber ➢ Engage snubber ➢ Close upper pipe rams
➢ Mud pumped through drill string via pressurized lower chamber ➢ Open upper pipe rams ➢ Disengaged sunbber Remove saver sub		➢ Mud pumped through drill string via pressurized lower chamber ➢ Pipe dope pin connection ➢ Pick up stand for connection

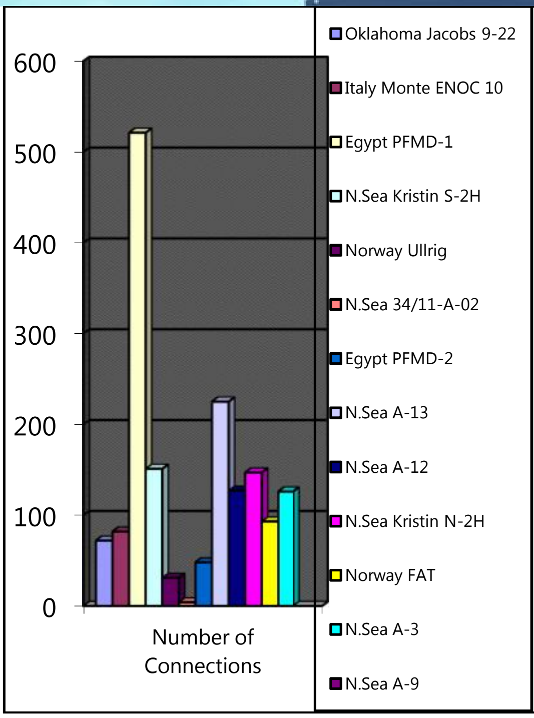
Fig.6: Sequence of Operations of CCS

5.1.1. CCS connection description:

The CCS consists of a pressure chamber containing two pipes and a blind ram which is placed in between the two pipe rams. During a connection the chamber is filled with mud equalizing the pressure inside and outside the drill string. Pipe rams will later on close around the drill pipe. After this is done the pipes are disconnected and the blind ram is closed. The upper part of the chamber is bled of, and the pipe removed. The circulation of mud is now made through the lower part of the pressure chamber and down the drill pipe, see figure 4. New stands of pipes are prepared and inserted in the upper chamber. The pipe ram is closed around the new pipe stand, and the chamber is pressurized. Mud is circulated through the new joint of pipes, the blind ram is opened, and the drill pipes are connected.

5.1.2. CCS connection procedure:

1. Lift the pipes.
2. Activate the pipe rams and the pipe slips.
   (a) Activate the pipe rams.
   (b) Activate the pipe slips.
3. Pressurize the chamber.
4. Connect the snubbing unit.
5. Disconnect the pipes.
6. Lift the upper pipe.
7. Close the blind ram.
8. Depressurize the upper chamber.
   (a) Seal the standpipe.
   (b) Open the drain valve to the upper chamber.
   (c) Bleed off the standpipe.
9. Disconnect the snubbing unit and the upper pipe ram.
   (a) Disconnect the snubbing unit.
   (b) Open the upper pipe ram.
10. Remove the pipe, and add new the pipe joint.
   (a) Remove the pipe.
   (b) Add new pipe joint.
11. Close the pipe ram, and connect the snubbing unit.
   (a) Close the pipe ram.
   (b) Connect the snubbing unit.
12. Close the drain valve to the upper chamber.
13. Pressurize the upper chamber.
14. Open the blind ram.
15. Connect the pipe joint and the drillstring.
   (a) Lower the pipe joint.
   (b) Connect the pipe joint to the drillstring.
16. Close the valve to the lower chamber.
17. Bleed off the chamber.
18. Close the drain valve.
19. Disconnect the snubbing unit.
20. Disconnect the pipe slips.
21. Open the pipe rams



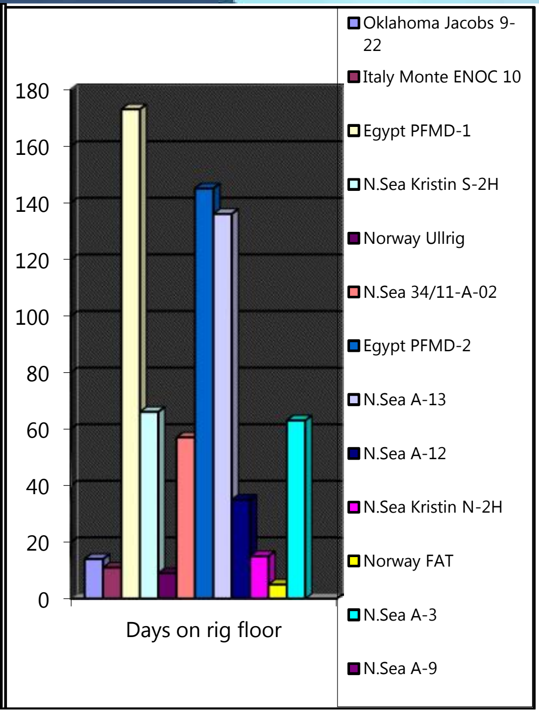
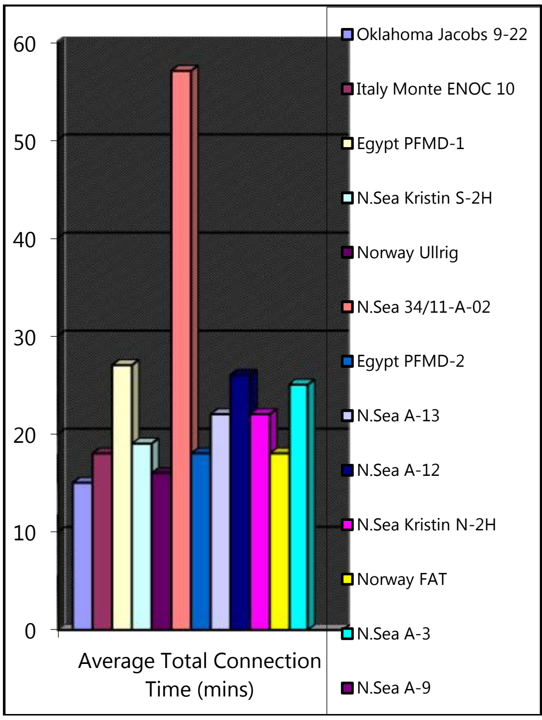


Fig.7:number of Connections **Fig.8: Rig floor days**



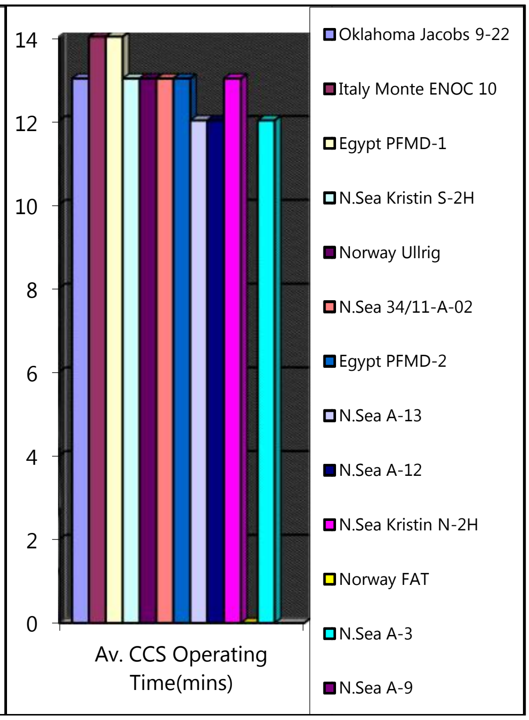


Fig.9: Total average connection time **Fig.10: Average operating time**

Depending on the situation and professionalism of CCS crew may reduce connection time.

Table 1: Performance Report of different companies using CCS

NUM	Operator	Date	Well	Number of Connections	Days on rig floor	Av. Total Connection Time (mins)	Av. CCS Operating Time(mins)
1	BP Americas	07/03 to 08/03	Oklahoma Jacobs 9-22	72	14	15	13
2	ENI Italia	5-Mar	Italy Monte ENOC 10	82	11	18	14
3	ENI/ Petrobel	06/05 to 11/05	Egypt PFMD-1	521	173	27	14
4	Statoil Hydro	12/05 to 03/06	N.Sea Kristin S-2H	151	66	19	13
5	Statoil Hydro	6-Jun	Norway Ullrig	31	9	16	13
6	Statoil Hydro	6-Sep	N.Sea 34/11-A-02	4	57	57	13
7	ENI / Petrobel	09/06 to 01/07	Egypt PFMD-2	48	145	18	13
8	Statoil Hydro	03/07 to 07/07	N.Sea A-13	225	136	22	12
9	Statoil Hydro	10/07 to 11/07	N.Sea A-12	127	35	26	12
10	Statoil Hydro	02/08 to 03/08	N.Sea Kristin N-2H	147	15	22	13
11	Unit 3 FAT	8-Jun	Norway FAT	93	5	18	N/A
12	Statoil Hydro	10/08 to 11/08	N.Sea A-3	126	63	25	12
13	Statoil Hydro	Current	N.Sea A-9				

5.1.3. Safe operability analysis of connection during CCS in Kvitebjørn platform

Kvitebjorn is a HPHT well located in the North Sea. The reservoir consists of sandstones in the Middle Jurassic Brent group, and lies at approximately 4000 meters depth [5]. There are a total of 11 wells where 7-8 at the moment is drilled. Production in the Kvitebjørn field has lead to lower fracture and pore pressure in the formation. Some places high pore-pressure zones are in the formation, leading to a narrow and difficult drilling window to predict and drill [6]. For further development it will not be economical favorable, or in some cases even possible, to drill conventional. In order to cope with the difficult conditions at Kvitebjørn MPD technology with use of a continuous circulation system, CCS is planned. CCS utilizes a circulation system in order to join drill pipes to the drill string without interrupting the drilling process [7, 8]. For Kvitebjørn this operation has never been performed before. With use of new technology there will always be a certain risk. In order to identify hazardous events, a SAFOP analysis was performed on a connection with use of a continuous circulation system. SAFOP is an examination of an existing or planned operation procedure to identify hazards and causes of operational problems, quality problems, and delays [9]. SAFOP is the process, which was based upon review of system piping and instrumentation diagrams (P&IDs). The method further developed to review the safety and operability of more complex activities [10]. The SAFOP analysis is usually performed on a process or operation in an early phase in order to influence the design. However it is also applicable on existing operations or processes to identify modifications that should be implemented in order to reduce risk and operability problems. It is a systematic and qualitative method based on guide words to identify deviations from the design intent [11]. The analysis is performed during a set of meetings by a HAZOP group consisting of; a leader, a secretary, and 4-6 technical experts [12, 13, and 14].

5.2. Mud Diverter Unit (MDU)

Is connected to the Bypass Manifold located in the delivery line between the main rig mud pumps and the derrick standpipe. The MDI-I switches the flow of drilling fluid between the Top Drive and the CCS during the connection process.

5.3. Top Drive Interface

Top Drive Interface has three components:

a) Top Drive Extension/Wear Sub or "Saver Sub-which is about 8 Ft (3m) long. The sub is locked to the bottom of the Top Drive and reaches inside the Main unit to position the connection.

b) Top Drive Connection Tool (TDCT) is suspended below the Top Drive at the level of the saver sub tool joint, and used to make or break the connection between the saver sub and the stand of drill pipe in the derrick.

c) Dual Sided Elevators are suspended below the TDCT, and are used to pick-up and handle drill pipe stands in the derrick. They can be opened on one side to Latch around a stand as it is being pulled through the system at the rig floor level and opened on the opposite side by the derrick man to rack or pick-up a stand in the derrick. CCS can be used to drill with open annulus returns or in conjunction with MPD rotating BOF, closed annulus systems.

5.4. Control Panel Human Machine Interface (HMI)

Control system is fully automatic enabling trained technical personnel to safely and efficiently operate CCS. The system has built-in safety alarms, manual interlocks between activities and ability to reverse or undo steps in operating procedures is located at the driller's position through which all system functions are controlled via a touch screen interface. It is self-checking but it can be interrupted at any stage and activity can be reversed by the operator. Most important of all it is safe for all personnel involved. All pipe handling (by snubbing jack) and break-out/make-up (by CCS unit) are done without direct manual interference. It is extremely important to train the personnel and ensure proper communication between the driller and CCS operator. The operations done in Kvitebjørn (Statoil Hydro) shows that having the crew trained on how to make connections has become the most time consuming part of the training.

5.5. Control Container

Control Container contains the system's Hydraulic Power Unit (HPIJ). HPIJ and the "black box" recorder which gathers and stores data on the system's operation.

6. CCS Rig-Up

CCS unit is pretty massive and a heavy equipment. It is therefore landed on the drill floor. Flow lines, hoses and other related equipment are also handled on the drill floor. The system is operated by trained drill crew using automatic means. Manual interference of any member of drill crew is possible if necessary. Dedicated rules and procedures should be followed up if manual interference necessitates. Below the drill floor is rig-up of conventional drilling equipment and system

CCS unit is very expensive and there is only one supplier (National Oil Varco) for the time being. CCS unit has the following dimensions

- Base : 5 x 6 ft (1.5 x 1.8 m)
- Height : 6 ft (1.8 m)
- Extended height : 12 ft (3.6 m)

System requires enough space and height in the rig. Lack of enough height for CCS may allow for drilling with singles or two pipe joints but not pipe stands. In such circumstances, more time may be spent for drilling and drilling procedures may need to be changed. Due to such reasons, CCS may not be applicable in all drilling rigs.

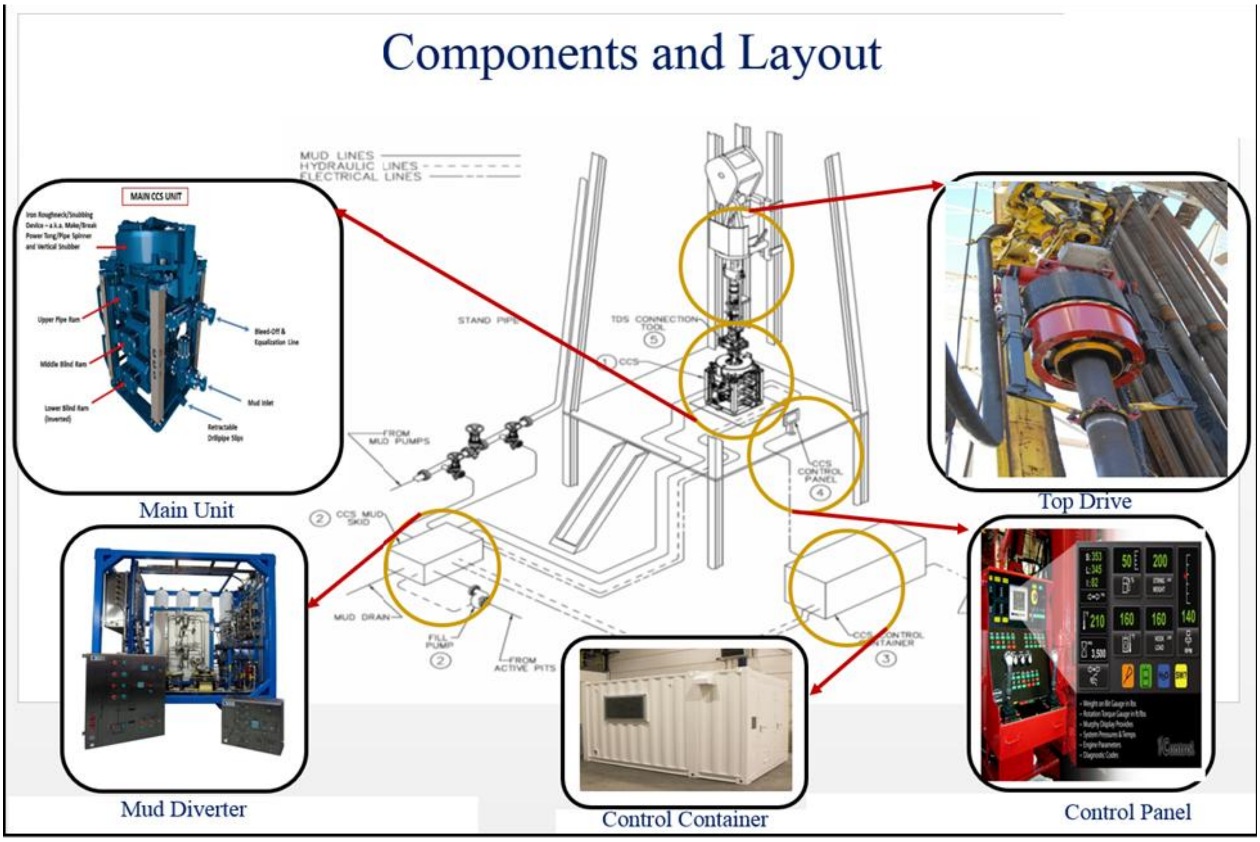


Fig.11: Showing the main components of CCS on the rig placement

7. CCS in Iran

According to studies made by the American Petroleum Institute (API) and the Minerals Management Service (MMS), 25% to 33% of all remaining undeveloped reservoirs are not drillable using conventional overbalanced drilling, OBD, methods. This is due to increased likelihood of well control problems such as differential sticking, lost circulation, kicks, and blowouts [15]. In addition, many depleted wells which still contain petroleum reserves could be utilized with alternative technologies to OBD. The challenge to the industry is to seek an efficient method to drill and develop these reservoirs in a manner that is eliminate or minimize formation damage, minimize costs related to the well and no less safe than the overbalanced drilling method.

In Iran the majority of hydrocarbon reservoirs are carbonates and some of them are fractured. Therefore conventional drilling can cause severe and complete losses of mud and drilling costs will be very high. Due to specific characteristics of the reservoir rock and fluid, many onshore oil fields such as Karanj, Parsi, Gachsaran, Bibihakimeh, etc. are candidated for drilling with CCS technology. Also in the shared fields in the Persian Gulf that require long horizontal extended reach drilling, using of this technology can make a substantial contribution to reducing drilling costs.

8. Nomenclatures:

- BHA - Bottom hole Assembly
- BHP - Bottom hole Pressure
- BMP - Balanced Mud Pill
- BOP - Blowout Preventer
- CCS - Continuous Circulating System

- Cs/K - Cesium' Potassium
- ECD - Equivalent Circulating Density
- EMW - Equivalent Mud Weight
- ERD - Extended Reach Drilling
- HAZID - Hazard Identification
- HAZOP - Hazard and Operability Study
- HPHT - Hazard and Operability Study
- JIP - Joint Industry Project
- LWD - Logging While Drilling
- MPD - Managed Pressure Drilling
- MWD - Measurement While Drilling
- OD - Outside Diameter
- PCWD - Pressure Control While Drilling
- RCH - Rotating Control Head
- RPM - Rotations per Minute
- S_g - Specific Gravity
- TD - Total Depth
- TDCT - Top Drive Connection Tool

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