

A Downhole Tool for Reducing ECD

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Abstract

The equivalent circulation density reduction tool (ECDRT) is designed to counter the increased fluid pressure in the annulus caused by friction loss and cuttings load by reducing the total hydrostatic head. The tool has a broad range of drilling applications, including: narrow-pore/fracture-pressure margins in deep water and their effects on casing setting-depth selection; wellbore instability; depleted reservoirs; and extended-reach wells.

This paper describes progress on development and testing of a prototype ECDRT. The prototype was recently tested in a BP onshore U.S. Arkoma asset operation in southeastern Oklahoma. The primary objectives of the field trial were: 1) determine ECD reduction performance; 2) establish reliability in field conditions; and 3) evaluate the ECDRT operational procedures. The test involved drilling 8.75-in. hole with the tool running inside 9.625-in. casing cemented at a depth of 4,500 ft. Performance was monitored continuously from a real-time display of surface and downhole measurements.

Wellbore pressure management was clearly demonstrated in the field trial. The ECDRT consistently reduced ECD by about 150 psi, or the equivalent of about 0.7 ppg at 4,500 ft. Drilling performance was not limited in any way by the ECDRT. Fluid returns and wellbore cleaning were normal throughout the drilling operation. The ECDRT processed cuttings generated by the drilling at 100 ft/hr without difficulty. More than 500 ft of hole was successfully drilled before the tool was pulled because of difficulties with the directional drilling system. The final goal to evaluate ECDRT operational procedures was achieved, as performance indicators on the surface worked reliably to diagnose the operational status of the tool.

Post-well analysis showed that there were still some design issues to secure the longevity and sustained performance of the tool. However, the tool demonstrated the ability to manage annular pressure under actual drilling conditions.

Introduction

The downhole pressure of circulating fluid is the sum of hydrostatic head (a function of mud density and cuttings loading) and frictional loss (a function of mud rheology, mud density, annular geometry, and flow rate). Managing downhole pressure is a critical element of most drilling jobs,

and it becomes paramount under difficult conditions of deepwater and extended-reach drilling (ERD). Often narrow margin between pore-pressure and fracture-pressure gradients leads to multiple problems such as circulation loss, differential sticking, and the tendency of the well to pack off when the circulation is stopped^{1,2}. Managing the ECD in the ERD wells is essential for reaching the target depth. While deepwater drilling is faced with many of the same challenges, weak formations and pressure variations along the well trajectory impose additional risks³. While much can be done to optimize wellbore hydraulics by appropriate selection of rheology and flow rate, many complex wells are still left with the challenge of managing excessive ECDs.

The objective of ECD reduction is to minimize the effect of pressure loss caused by friction so that downhole pressure of circulating drilling fluid is nearly equal to its hydrostatic pressure. Some of the benefits of ECD reduction are: ability to drill challenging wells to their target depths; extended casing shoe intervals; increased safety margin between fracture gradient and actual ECD; improved rates of penetration (ROPs); and enhanced wellbore stability⁴.

This paper describes the development of a downhole tool for reducing the ECD of circulating mud. It covers the design and testing of a prototype ECDRT that is potentially valuable for both onshore and offshore applications. The prototype has been put through extensive technology tests in an experimental well and two field trials. Lessons learned from technology tests and successful field trials have been incorporated into the current design. The results from technology tests and field trials are presented in this paper together with the forward plan for making the technology available to the marketplace.

Description of the ECDRT

The ECDRT consists of three sections. At the top is a turbine motor that draws hydraulic energy from circulating fluid and converts it into mechanical energy. The turbine drives a multi-stage pump which adds energy to the return fluid, creating the required pressure differential in the annulus. The turbine is matched to the pump, and both run at the same speed. The lower section of the ECDRT consists of annular seals to ensure that all return fluid and cuttings pass through the pump. The annular seals remain in constant contact with casing. They are supported on bearings so that the annular

seals do not rotate with respect to the casing when the drillstring is rotated. Design specifications of the ECDRT are given in **Table 1**.

The ECDRT is a self-activated tool, powered by the circulation of drilling fluid. It starts automatically when the fluid is circulated, and it stops running when the circulation is cut off. The tool is designed to handle a wide range of drilling fluids with density of up to 15 ppg (1.8 SG), inclusive of drill cuttings. The current prototype has an 8.20-in. outside diameter (OD) and can be run inside casing strings from 9-5/8 in. (47 lb/ft or lighter) to 13-3/8 in. The ECDRT can handle circulation rates up to 600 gpm. Additional tool sizes, designed to operate in different hole sections and with a wider range of flow rates, will be made available once the technology is commercialized.

Table 1. Specifications of the ECDRT

Outside diameter	8.20 in. (208.3 mm)
Inside diameter (ID) (through-bore)	1-13/16 in. (46 mm) after retrieving a flow diverter with wireline
Length	30 ft (9.15 m)
Weight	2,600 lb (1,178 kg)
Mechanical strength	Equal to or higher than that of 5.0-in., 19.5-lb/ft S-135 new drillpipe
Top connection	4 1/2-in. IF box
Bottom connection	4 1/2-in. IF pin
Applicable in casing sizes	9-5/8 through 13-3/8 in.
Maximum fluid circulation rate	600 gpm (2,270 L/min)
Maximum makeup torque (MUT)	30,000 ft-lb (40,600 N•m)

The ECDRT is a portable tool that can be installed in the drillstring, as needed, by making a short trip. The ECDRT is operated in the vertical section of the well, starting at less than 700 ft from the surface. This relatively shallow placement of the tool is significant, as it not only allows for rapid installation but ensures a limited effect on drilling activities. Deployment of the ECDRT requires virtually no rig-up time.

Prototype Lab Testing

A prototype ECDRT was extensively tested in a flow loop and in an experimental well. The objectives of the tests included:

- Determine the performance envelope for different water-based drilling fluids and flow rates.
- Study cuttings transport through the pump.
- Study the effect of reverse flow of fluid (bullheading) through the pump.
- Study the effect of lost-circulation materials (LCM).

- Test the compatibility of the ECDRT with mud-pulse telemetry used in measurement-while-drilling (MWD) tools.
- Study downhole transient pressure spike at startup of rig pumps.
- Study surge and swab.
- Study downhole pressure reduction.
- Study functionality of the tool in a simulated drilling environment.
- Study longevity of the tool operating at normal circulation rate and standpipe pressure.

Testing in a Flow Loop

The first four tests were conducted in a specially designed flow loop. The configuration of the flow loop varied slightly from one test to another. The ECDRT was placed in a test chamber made from 13 3/8-in., 72-lb/ft casing. For Test No. 1, two triplex pumps were used in tandem to obtain fluid circulation rates of up to 600 gpm. An adjustable choke, located downstream of the ECD pump, was used for creating backpressure to simulate hydrostatic head in the annulus. Fluid pressure was recorded at the inlet of the turbine and at the inlet and outlet of the pump. The fluid circulation rate during the tests varied from 175 to 550 gpm. Fluid density varied from 8.3 ppg (1.0 SG) to 12.6 ppg (1.5 SG).

Fig. 1 shows a plot of pump boost pressure as a function of flow rate and mud density. A positive pressure boost refers to a pressure reduction in the annulus by the same amount as a result of the functioning of the ECDRT. The data show the pressure boost to be negative at low rates (<200 gpm) because the ECDRT acts as an annular restriction before operating at its minimum flow rate. The maximum negative pressure boost recorded was about 50 psi. When the tool started working, pressure boost increased steadily in a quadratic manner as the flow rate was increased. Increasing fluid density proportionately increased pressure boost from the ECDRT. For example, at 550 gpm circulation rate, pressure boost was 275 psi for water and 425 psi for 12.6-ppg (1.5-SG) drilling fluid.

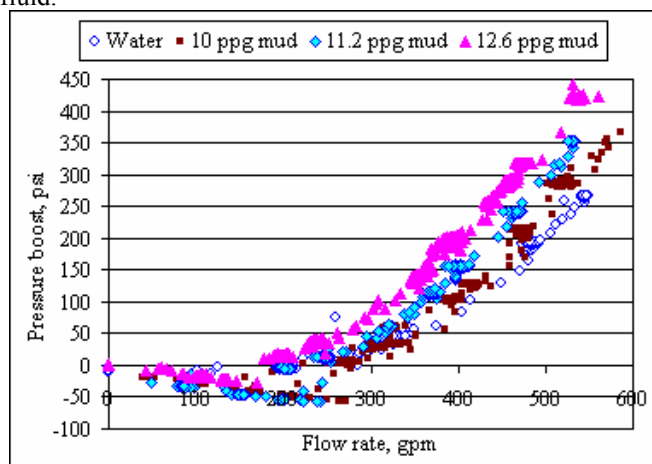


Fig. 1. Pressure Boost Data as a Function of Flow Rate and Mud Density

Pressure boost data from Fig. 1 were converted into the potential effect on the ECD as a function of drilling fluid density and vertical depth of the well (**Fig. 2**). In a relatively shallow well, such as an ERD well, the ECDRT would cause much greater ECD reduction than in a deep well.

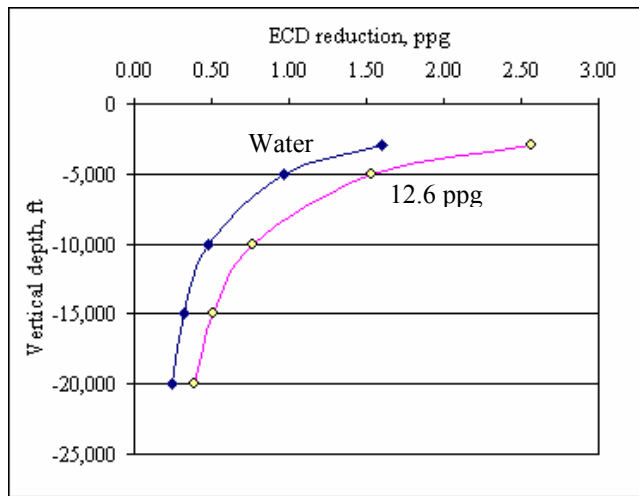


Fig. 2. Potential Benefit of the ECDRT as a Function of True Vertical Depth (TVD)

Test No. 2 was conducted by adding plastic balls of 0.25-, 0.31-, 0.375-, and 0.5-in. diameters to the drilling fluid to simulate actual drill cuttings. The fluid containing plastic balls was circulated through the pump for 45 minutes. The pump was dismantled after this test to check for plugging and damage to internal components.

The tests with plastic balls did not indicate any problem, and balls up to 0.31-in. diameter passed smoothly through the pump. There was no noticeable damage to any of the internal components. As discussed later, the ECDRT has been put through two field trials, and cuttings transport through the pump has not been a problem.

The ECDRT is expected to be operated in areas where the tight pore-pressure/fracture-pressure window might dictate the need for bullheading fluids in the event of a well control incident. For Test No. 3, fluid was pumped into the ECD pump in the reverse direction to simulate a bullheading operation. The bullhead test was performed with 13.3-ppg water-based drilling mud having plastic viscosity of 11 cP and yield point of 28 lbf/100 ft². The maximum flow rate was 550 gpm, going through the ECDRT pump in the reverse direction. No tool plugging was observed, indicating that bullheading is possible while the ECDRT is in the well.

The LCM test (Test No. 4) was conducted with carbonate and graphite added to 12.6-ppg water-based drilling fluid at up to 50 lb/bbl. The presence of LCM in the fluid had no adverse effect on running and performance of the ECDRT.

Tests in the Experimental Wells

Test No. 5 was necessary for ascertaining that the ECDRT would not hinder directional drilling data acquisition during

the drilling operation. This test was conducted in an inclined well. The ECDRT was located in the vertical section of the well, 300 ft from surface. The MWD tool was 1,000 ft from the ECDRT, farther down the well. Tests were conducted for both positive pulse and negative pulse telemetries. Known inclination where the MWD tool was located in the well was compared with well inclination recorded at the surface. No difference between the two observations confirmed that the ECDRT did not degrade mud-pulse telemetry. This finding was later verified at greater distances during the field trials.

The remaining tests were conducted in a vertical well. For Tests No. 6 through 9, a 10 3/4-in., 45.5-lb/ft casing string was run in the well to 1,415 ft. Two lower joints were filled with cement before being run into the well. Functional performance and cuttings transport tests were conducted with 9.40-ppg (1.13-SG) water-based drilling fluid by drilling the cement column from the casing with a 9.5-in. tri-cone bit powered by a 6.5-in. downhole motor. To measure downhole pressure reduction with the ECDRT, pressure sensors were installed in the casing collars at 1,220 and 1,080 ft. This arrangement allowed real-time measurement and display of pressure in the annulus below and above the ECDRT.

Drilling of the cement column went well except that the ROP was less than hoped for because of inadequate weight on the bit. **Fig. 3** shows the effect of the tool on the ECD calculated from downhole pressure recorded at 1,220 ft. Some of the noise in the ECD data points to movement of the drillstring during the test. At a 550-gpm circulation rate of 9.40-ppg drilling fluid, ECD varied from 6.4 to 6.7 ppg. The pressure spike at the start of rig pumps was typically less than 30 psi. Downhole pressure surge during trip-in and the swab effect during trip-out varied with trip speed.

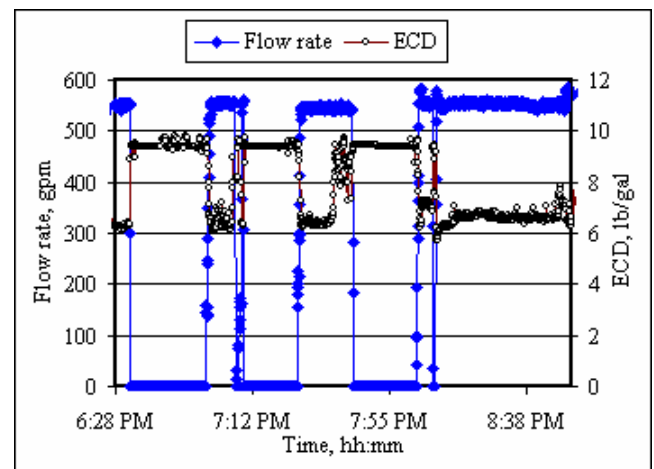


Fig. 3. Results from Functionality Test in an Experimental Well

After various tests were completed, the tool was subjected to a 40-hr longevity test (No. 10). The main objective of the test was to determine performance and endurance of the tool when run at relatively high (3,500- to 3,700-psi) standpipe pressure.

The longevity test was conducted with the tool running inside a 9 5/8-in., 43.5-lb/ft casing string. The ECDRT was located at 605 ft from the surface. Density of drilling fluid was 9.10 ppg (1.10 SG). The fluid circulation rate varied from 470 to 508 gpm. The tool was run continuously for 40 hr except for short stoppages for unrelated reasons.

The 40-hr longevity test was successfully completed, as there was no noticeable performance loss or mechanical problem. Fig. 4 shows that the annulus pressure below the tool, recorded at 611 ft, was 294 psi at no circulation, 188 psi at a 470-gpm circulation rate, and 165 psi at a 508-gpm circulation rate. Annulus pressure data were converted into ECD at 1,400 ft (bottom of the well). The effect of the ECDRT was reduced ECD to 7.4 ppg for 9.1-ppg drilling fluid. A small pressure spike of 25 to 30 psi was noticed just at the start of rig pumps, which was consistent with results from earlier flow loop testing (Fig. 1).

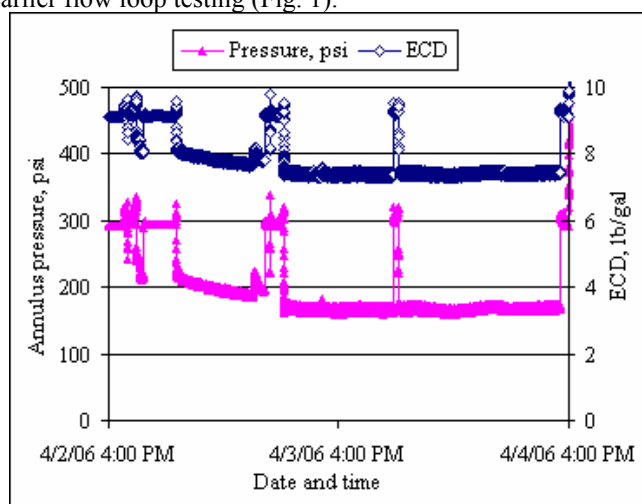


Fig. 4. Results from a 40-hr Longevity Test in an Experimental Well

Field Trial Execution and Results

The ECDRT has undergone two field trials in BP operations in Oklahoma (Table 2). The field trials had three primary objectives: 1) determine ECD reduction performance; 2) establish reliability in field conditions; and 3) evaluate the ECDRT operational procedures. In the first field trial, the ECDRT was run inside a 10 3/4-in., 45.5-lb/ft casing string; and in the second field trial, it was run inside a 9 5/8-in., 40-lb/ft casing string. Drilling fluid used was 9.5-ppg oil-based mud. The circulation rate varied between 525 and 550 gpm in the first field trial and between 540 and 570 gpm in the second field trial. The performance of the tool was monitored continuously from a real-time display of surface measurements for standpipe pressure, hook load, circulation rate, mud return, and ROP. In addition, a downhole annular pressure measurement tool was used for real-time display of ECD.

During the first field trial, estimated ECD without the ECDRT for 9.50-ppg drilling mud was 9.70 ppg. The actual ECD measured with the downhole pressure tool varied from

8.6 to 8.7 ppg (Fig. 5). Thus the effect of the ECDRT was estimated as 1.0- to 1.1-ppg ECD reduction. A total of 140 ft was drilled with the ECDRT when the data stream for ECD started showing unstable trend. Shortly thereafter the ECD suddenly increased to 10 ppg, indicating a problem with the tool. At that point the decision was made to conclude the field trial and retrieve the tool for inspection. The inspection of the tool showed that one of the seals had failed, leading to seizure of bearings.

Table 2. A Summary of Two Field Trials of the ECDRT

	First field trial	Second field trial
Date	Nov 2004	Jun 2006
Location	BP Anadarko	BP Arkoma
Casing size	10-3/4 in.	9-5/8 in.
Casing shoe depth	5,480 ft	4,500 ft
Drilling fluid	Oil-based, 9.5 ppg	Oil-based, 9.5 ppg
Bit size	9-7/8 in.	8-3/4 in.
ECDRT starting depth	546 ft (166 m)	650 ft (198 m)
Successfully drilled	140 ft (42.6 m)	>500 ft (152.0 m)
Reason for ending field trial	Sudden increase of ECD	Performance deterioration

The average ROP during the drilling was 38 ft/hr. Cuttings generated from drilling flowed through the ECDRT without causing any plugging. The mud-pulse telemetry also worked without any noticeable signal attenuation. The surge and swab pressure effects were managed by controlling trip speeds.

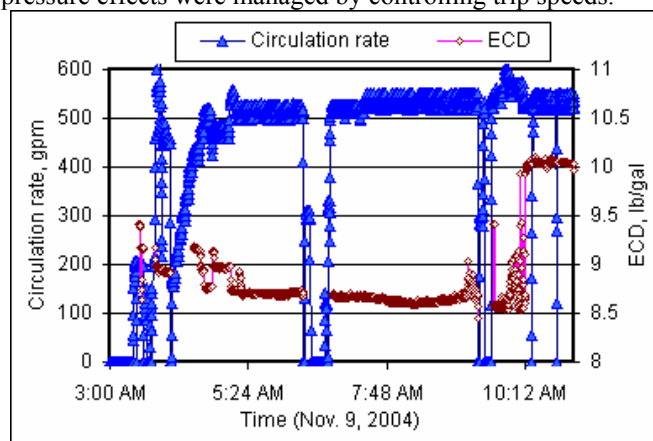


Fig. 5. ECDRT Performance Results from the First Field Trial

In the second field trial, more than 500 ft of formation was

successfully drilled with the ECDRT at an average ROP of 100 ft/hr. The tool showed no signs of plugging with cuttings. Running and retrieving operations also went smoothly, just as they did in the first field trial. Pump start-up, swab and surge pressures were kept below 30 psi with good operational practices. Thus in both field trials objectives 1 and 3 were fully achieved. Performance indicators on the surface worked reliably to diagnose the operational state of the tool.

Estimated ECD without the ECDRT during the second field trial was 10.2 ppg with a 9.5 ppg mud. Initially ECD with the ECDRT varied between 9.3 and 9.5 ppg (**Fig. 6**), which showed approximately 0.7-ppg ECD reduction by the tool. This ECD reduction corresponded to a decrease in bottomhole pressure of approximately 150 psi; however, during the course of drilling, the ECD gradually increased to 10 ppg, indicating deterioration of tool performance. A decision was made to pull the tool early to diagnose the problem without risking damage to the tool and to eliminate any potential downside to the drilling operation.

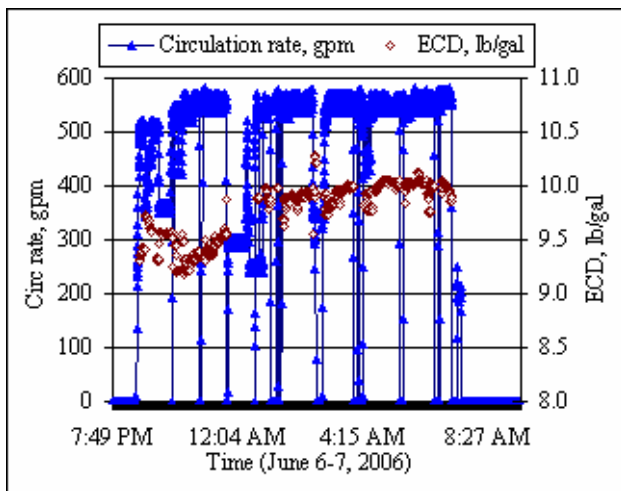


Fig. 6. ECDRT Performance Results from the Second Field Trial

Subsequent inspection of the tool showed two significant design issues. First, some of the rotating parts exhibited too much wear, which caused excessive bypass of drilling fluid from the drillpipe to the annulus. The ECDRT has a design feature that allows a small leakage of drilling fluid from inside to the annulus at two locations. Typically the total leak rate should be less than 25 gpm. During the field trial, initially the fluid leak rate was slightly more than 25 gpm; however, within a few hours of running the tool, the leak rate from the ECDRT increased to an unacceptable limit. The leakage had an adverse effect on the operation of other downhole tools in the bottomhole assembly (BHA). The second problem was the failure of the annular seals, which greatly affected the performance of the ECDRT. Design changes to alleviate the above problems are currently in lab testing. The forward plan is to incorporate design modifications in the tool, perform an additional 40-hr longevity test in a test well, and conduct more field trials. Commercialization of the tool is anticipated to begin in the third quarter of 2007.

Summary and Conclusions

High ECD is a significant problem in deepwater drilling and in ERD wells because of narrow pore-pressure and fracture-gradient windows. Much can be done to optimize hydraulics by the appropriate selection of fluid rheology and flow rates; however, sometimes excessive ECDs make these wells very challenging. Under such conditions the ECDRT has the potential to alleviate or totally eliminate ECD-related problems.

- Results from tests conducted in a flow loop and in an experimental well have shown that the ECDRT can provide up to 450-psi pressure relief in the annulus.
- The pressure relief in the annulus corresponds to a significant ECD reduction, which is a function of the vertical depth of the well.
- The results from field trials have proved the viability of using the ECDRT to manage ECD.
- Adding the ECDRT in the drillstring required tripping out only seven stands.
- Surge and swab pressure effects were managed by controlling trip speeds.
- Cuttings generated from drilling flowed smoothly through the ECDRT. Similarly, mud-pulse telemetry worked flawlessly.
- At the end of the most recent field trial, there were still some design issues regarding excessive wear on specific parts and damage to annular seals.
- Additional development and testing is under way to improve longevity of the tool. Additional field trials are expected in early 2007.

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