



## IADC DUAL GRADIENT DRILLING WORKSHOP

Madrid, Spain

April 7, 2014

### DGD System Attributes

	PRE-BOP	POST - BOP				
DGD System	Mudline Pumping (Riserless)	Seabed Pumping		Dilution	Controlled Mud Level	
Technology Name	RMR™	Max Lift Drilling (previously SMD)	CMP™	CAPM™	EC-Drill™	EC-Drill+
Technology promoting company(ies)	AGR Enhanced Drilling	Chevron / GE / Pacific Drilling / AGR	AGR Enhanced Drilling	Transocean	AGR Enhanced Drilling	AGR Enhanced Drilling
Shallow Hazard Mitigation Well Construction	Y	N	N	N	N	N
Top hole mud & Cuttings Recovery						
Ultra-Deepwater tight pressure margins	N/A	Y	Y	Y	Y	Y
Abnormal pressures	N/A	Y	Y	Y	Y	Y
Closed system with RCD?	N	Y	N	Y	N	N
Normal/Subnormal pressures	N/A	N	N	N (Riser Injection) Y (Below Seabed Injection)	Y	Y
Reduces # of casing strings	Y	Y	Y	Y	N	Y
<b>MECHANICAL</b>						

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Top Fluid, Static conditions	Seawater density	Seawater density	Seawater, base oil, or Inert gas atmospheric pressure	Diluted well fluid	Riser full / atmospheric pressure	Inert gas atmospheric pressure
Top Fluid, Dynamic conditions	Seawater density	Seawater density	Inert gas or air	Diluted well fluid	Inert gas or air	Inert gas or air
Well Fluid	Higher than conventional density mud	Higher than conventional density mud	Conventional or higher than conventional density mud	Higher than conventional density mud	Conventional mud density	Higher than conventional density mud
Pump Location	Near Seabed	In-line above LMRP	Near Seabed/mid riser	Not Applicable	Suspended or riser fixed 1200ft below sea level	Suspended or riser fixed Mid water
Pump Type	Head	Positive Disp.	Head	Not Applicable	Head	Head/PD
Fluid Entry Point	Wellhead	Near seabed	Riser/Choke line	Riser (booster line)	Riser	Riser
Power source	Electrical	Surface seawater pump	Electrical	Surface mud pumps	Electrical	Electrical
Electrical power to pump (and purpose)	Case Dependent	~100 hp (for HPU's)	Case Dependent	Not Applicable	Case Dependent	Case Dependent
Riser Modifications	N/A	Mud return and seawater power lines	One Modified Riser Joint Modified Choke Line	Upper Riser Flow Control Equipment	One Modified Riser Joint	Two Modified Riser Joints + Riser Annular (gas handler)

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Surface mud treatment	Standard	Standard	Standard	Centrifuges	Standard	Standard
Closed System (RCD in place)?	N (Optional)	Y (desired, but optional)	No (Closed Annular BOP circulating Kick out)	Y	N	No (Closed BOP circulating Kick out)
Rotating Control Device location	At wellhead (if used)	Near mudline	None	Within Upper Riser Flow Control Equipment	None	None
Flow Arresting Valve in BHA?	N (optional)	Y (optional)	Y (optional)	Y (optional)	Y (optional)	Y (optional)
Maximum Water Depth	5000'	10,000'	5,000'/All	10,000'	All	All
Max flow rate at max WD (gpm)	1200 gpm	1800 gpm	1600 gpm	3,000 gpm	1600 gpm	1600 gpm
Maximum mud density (ppg)	14	18.5	Depth Dependent	18.5	18.5	18.5
Max flow rate @ max WD & MW	1200gpm / 12.5 ppg in 5000'	850 gpm/18.5 ppg in 10,000' WD	Depth Dependent	Drilling Fluid: 1,500 gpm / 12-18 ppg Returns: 3,000 gpm / 9 to 14 ppg	Depth Dependent	Depth Dependent
Minimum Water Depth (functional/practical/economical)	100'	3,000'	3000'	3,000' 0' (Below Sea Bed Injection)	300'	600'
<b>OPERATIONAL</b>						
Variable interface level	N	N	Y	N	Y	Y
Variable top fluid density	N	N	Y	Y	N	N
Cuttings size limit	2,5"	None	2.5"	None	2.5"	2.5"
<b>WELL CONTROL</b>						
Specialized well control required?	N	Y	Y	Y	N	Y
Is full riser margin restorable?	N/A	Y	Y	N		Y (case

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				(Riser Injection) Y (Below Sea Bed Injection)	N	dependent)
WC method (Driller's, Bullhead, Engineer's)	N/A	All, plus volumetric and dynamic kill	All	All	All	All
Kick detection method	Pump Speed/power	Pump speed if circulating, flow while static if not	Pump Speed/power &/or flow meter Control System with delta flow measurement	Closed system, Secure Software & Coriolis Meters	Volume control (including riser level) and accurate flow rate out	Volume control (including riser level) and accurate flow rate out
Direct measurement SIDPP	N/A	Y, multiple methods	N	Y, multiple methods	Y	N
Use c/k lines for WC (y/n)	N/A	Y	N	Y (Drillers method) N (Modified Method)	Y	Y (part way) + SS Coke
WC fluids through pump (y/n)	N/A	Y	Y	Not Applicable	N	Liquids only
How high gas fraction is pumped	N/A	Slower pump rate	10% (free gas) max	Not Applicable	Not affected in WC events	Not affected in WC events
Friction losses seen by well	Y	N	N (ECD compensation)	Y (Drillers method) N (modified method)	N (ECD compensation)	N (ECD compensation)
Estimated smallest detectable	<2 bbls	< 2 bbls	<2 bbls	1 bbl	< 2 bbls	< 2 bbls

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influx		(demonstrated)				
Estimated max kill rate	N/A	>10 bpm	Case dependent	Method Dependent	N/A	Case dependent
Max circulation rate limitation	N/A	Gas handling	Gas handling	Friction losses / Gas Handling	Depends on procedure	Depends on procedure
<b>MATURITY OF SYSTEM</b>						
DGD Operations and WC Procedures fully developed?	Y	Y	Y	Y	Y	Y
DGD Ops/WC schools and simulator fully developed?	Y	Y	Y	Y	Y	Y
Number of people trained to date	> 20	~ 400	< 10	< 10	~30	< 10
Highest level of equipment testing: (none/component in shop/flow loop/field test components/field test system/well drilled/multiple wells drilled)	200 wells drilled	Well drilled in 2001. Subsea testing of commercial system ongoing Feb, 2014.	Need Pump Qualification	<u>Dilution principle</u> – flow loop test <u>Upper riser package</u> – Dry Run on DEN & similar package in use (MPD application from a DP Drillship) <u>Flow Stop Valve</u> – Flow loop and open water tested	3 DW wells drilled	Need SS choke Qualification – other Components same as EC Drill
Estimated first test system deployment date	Done 2004	10/2001	2013	2015	Done DW 2012	2015
Estimated first commercial deployment date	Commercial	2014	2015	2015	Commercial	2016
<b>TRAINING PROGRAM MATURITY</b>						

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Basic operations/well control	5 days (basic + RMR specific)	8 days	3 days introduction, 2 days specific course and 3 day written and simulator course	3 days	RMR training + 6 days specific course	5 days general + specific courses
Advanced well control	N/A	5 days. Written and simulator testing	Case specific Written and simulator testing	Case-specific	None	3-5 days Simulator Case-specific Test
Regulatory/Industry Endorsement	Commercial	IADC Accreditation received for Basic DGD Operations and Advanced Well Control Subsea option of WellCAP. Certificate will be required	Design reviews, rig owner, Operators	Learning Meetings with BSEE Review with Industry SMEs	Learning Meetings with BSEE 3 <sup>rd</sup> . party review, PETIL + drlg.contr.	Learning Meetings with BSEE 3 <sup>rd</sup> . party review, + drlg.contr.
Equipment classification/certification	Norsok Z-015 / DNV	ABS / DNV	DNV-OS-E101 Drilling facility	DNV DVR for Equipment Installation will require review dependent on MODU (ABS / DNV)	DNV-OS-E101 Drilling facility	DNV-OS-E101 Drilling facility
Peer review	Regulatory –endorsed 3 <sup>rd</sup> party review	Regulatory –endorsed 3 <sup>rd</sup> party review	HAZID/HAZOP Operators and DNV	Industry Accepted SME – Blade Energy Services	DNV per DNV-RP-A203 Qualification of new technology	Y

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					and HAZID/HAZOP	
Training media	E-Learning / Classroom / Computer	Classroom simulator, animations, physical model	Classroom, animation, simulator, real equipment	Classroom, animations, simulator	Classroom, simulator, Small-scale model, real equipment	Classroom, simulator, Small-scale model, real equipment

**Sources:**

- RMR: Roger Stave, AGR Enhanced Drilling
- MaxLift Drilling: Ken Smith, Chevron
- CMP: John Cohen, AGR Enhanced Drilling
- CAPM: Iain Sneddon, Transocean
- EC-Drill: Roger Stave, AGR Enhanced Drilling
- EC-Drill+: Børre Fossli, AGR Enhanced Drilling