Why “Do Not Disturb” Is a Safety Message for Well Integrity

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What we’ll explain
Other items may be mentioned

Macondo is the North Star for industry thinking about well integrity. In today’s presentation, we’ll ask old and new questions:

• What really caused of the influx of hydrocarbons?
• Why was the influx of fluids undetected?
• Upgrades to training curricula for cementing and well control?
• What are the effects on wellbore integrity and well control by:
  • Sealing the annulus at the wellhead during the WOC time period
  • Drilling fluid temperature changes reduce hydrostatic pressures
Why didn’t the rig crew detect the formation flows?

Our answer:

– *Information to the crew was cut off* when annulus was sealed by installation of the casing seal assembly within minutes after the placement of cement, while it was still a liquid!

– The crew therefore could not monitor annular fluid level changes and raise a well control alert!
When - and why - did formation fluids enter the wellbore?

Our answer:

1) Shrinkage caused by the cooling of drilling fluid in the annulus outside the casing induced formation fluid influx when the cement was still a fluid and not a barrier.

2) The fluids from the flowing zones diluted the cement and created permanent flow channels within two hours after cement placement.

3) No evidence of upward flow was found. Downward annular flow accounted for the flow path found inside the casing.
Let’s look at the time-line on Tuesday, April 20, 2010

- **00:40** – Top plug bumped at 1150 psi (1000 psi > circulating) with planned volume.
- **00:43** - Floats tested & held after 5 bbls flowback. Crew had no indication of losses. Post-job in/out data showed 80 bbls losses……likely into weak zones below 18215 ft.
- **01:00** - Casing seal assembly set & created an annular seal at the wellhead which blocked the hydrostatic pressure from the fluid in the riser.
- **01:00** – Progressive cooling of trapped SMB caused loss of hydrostatic head pressure & induced formation influx. The unset cement transmitted the HHP losses from the mud column thru the cement to the 5 flowable formations which underbalanced them.
- **03:00** – Fluids from flowing zones progressively ruined the cement’s sealing capability as flows travel down & likely enter weak zones below 18215 ft.
- **12:55** – Casing pressure test was successful indicating no breach in pressure integrity.
- **17:05** - Rising pressure differentials cause flow thru shoe track & up inside casing.
- **21:38** - Hydrocarbons pass the BOP and enter the riser
- **21:40** – Fluids blowout at rig floor & the rest is history

**NOTE: On Sept. 10, 2010, the cement top tested OK which indicated that formation flows traveled down the annulus to enter the casing. A “u-tube” test on Oct. 7, 2010 found no light fluids (hydrocarbons & nitrogen) in the annulus showing that “the nitrified cement slurry used in the annulus likely did not fail” (BSEE report 9-14-2011).**
How do we know that fluid volumes in closed containers respond to temperature?

When you have a fever, the mercury in the thermometer expands.

When the fever breaks, the mercury in the thermometer shrinks.

_In subsea wells and at Macondo, trapped fluids in the annulus below the casing seal assembly act like a giant thermometer._
How Does Mud Cooling Happen?
Contributed by Juan Garcia, retired Global Drilling Manager, ExxonMobil

Deepwater Well Shut-in Temperature Profiles after 8 days Circulation - Example
Mud Cooling Below Casing Seal in Macondo Well
Mud Cooling in Most of Annulus Converts Overbalance into Underbalance

Seafloor temperature is 33-36° F
Expanded View of Mud Cooling in Macondo Well

- Hot mud circulated up from bottom of hole
- Geothermal gradient

End of Cementing
10 Minute Shut-In
20 Minute Shut-In
30 Minute Shut-In
40 Minute Shut-In
60 Minute Shut-In
90 Minute Shut-In
120 Minutes
undisturbed

Depth ft

Temperature F

40 50 60 70 80 90 100 110 120 130 140
Pore Pressure Readings at Potential Flow Zones
LWD/MWD (Red Boxes) and WL Logs (Blue Box)

13,000 psi
14.20 PPGE

11,800 psi
12.60 PPGE
Formation Fluid Influxes Triggered by $\Delta T$

End of Cement Job & Set Casing Seal Assembly

Change in Synthetic Oil Mud Equivalent Weight Due to Cooling in Sealed Annulus

14.2 ppg pore pressure @ 17684'-17693'
13.0 ppg pore pressure @ 17788'-17791'
12.6 ppg pore pressure @ 18051'-18233'

Cooling temperature change $F$
Other Concerns and Lessons

- Four years of analysis and investigative reports had not identified the root cause for why reservoir fluids entered the annulus outside the casing, and, eventually, inside the casing and up the riser.

- Absent the destruction of the cement’s sealing capability during WOC, the cement job at Macondo might have served as an effective barrier against formation influx. The top part of the cement tested OK as a barrier.

- As differential hydrostatic pressures increased (> outside vs. < inside casing), the shoe track integrity failed which initiated abnormal pressures inside casing & drill pipe. Flows increased as time passed & mud removed.

- Conducting a Cement Bond Log (CBL) would have been too late, as the sealing integrity of the cement had been ruined during WOC and the blowout happened before the time to run the CBL. The lives of the logging crew would have been put at risk had they stayed on the rig to run the CBL as planned.

- Claims that the cementing job failed were dispelled by positive results in downhole barrier testing: pressure test, U-tube, & logging results.

- Negative cementing claims also trumped by finding underbalanced downward flows thru the cement before setting hard. All cementing jobs can fail under these conditions!!!
Key Safety Practices Not Discussed in Reports
Should be better explained in standards & regulations!

- API RP 65 says: “At all times during waiting on cement (WOC), activities that may disturb the cement should be minimized. The well must be observed for indications of flow and well-control contingencies must be executed.”

- RP 65 also says that during WOC, annular pressures have to be stable, below fracture pressures, and above formation pore pressures,
  - More should be said to emphasize that cement can not develop into a pressure barrier when exposed to unstable pressures.
  - In other words, kicks and losses should not occur during and after cementing and should be controlled prior to cementing.

- Not explicitly said in RP 65 is that casing seal assemblies and other sealing devices should not seal until after WOC time,
  - If set before WOC ends, losses and/or mud cooling can cause underbalanced pressures across flowable zones.
  - And rig crews can’t monitor fluid levels in the casing annulus.
  - Trapped pressure should be prevented during WOC and also checked for potential casing damage during deeper drilling.
What else can be done to improve safety?

- **A BETTER FLOAT VALVE DESIGN for HIGH PRESSURE APPLICATIONS**
  At Macondo, the highest reservoir pressure was ca.13,000 psi, but the rated pressure of the float valve was only 5,000 psi. New HPHT designs are needed to lower manufacturing costs, and industry should routinely plan on having float valves rated higher than worst case differential hydrostatic pressures. Side ports should be used to avoid plugging bottom ports.

- **CEMENT SEAL SENSOR PLACED ABOVE & BELOW FLOWABLE ZONES**
  New sensor tools would inform the drilling crew of any influx from the formation and of any fluid migration through the cemented annulus. The sensor technology that has been developed to verify cement barrier seals is limited, too costly, and intrusive (restricts flow).

- **BYPASS in CASING SEAL ASSEMBLY**
  The open bypass would allow the casing seal assembly to be installed shortly after the placement of cement. This flow bypass would temporarily allow continuous hydrostatic pressure transmission from the fluid column in the riser during WOC. After WOC time ended, the bypass would be closed. This would also enable monitoring of the fluid level in the riser annulus to detect kicks or losses during the WOC time period as the unset, fluid cement develops into a hard set, sealing barrier.

- **Real Time Operations Center in Offices to Monitor & Approve Tests & Stop Work**
  Subject matter experts to support joint decisions by rig & office management.
Conclusions – Take Away Lessons for Subsea Well Cementing Job Planning

• Run thermal modeling to check for undesirable results by wellbore fluid expansion or contraction during WOC and other operations. (Similar modeling already helps in designing wells to prevent pipe damage during production by trapped annular pressure.)

• Add calculations in thermal modeling to determine underbalances during WOC.

• Use pre-job thermal analysis to select mud conditioning volumes, drilling fluid properties, setting & sealing time for casing seal assemblies, top of cement depths, cement design (WOC times, etc.), and other procedures prior to, during, and after cementing operations.

• Static thermal simulations may also be advisable for other drilling operations such as tripping drill pipe, running casing/liners, wireline logging, negative pressure testing, and same during completion and workover operations.

• Lessons learned to be added to drilling safety courses taught on rigs and in classrooms and incorporated into industry standards and operators’ SOPs.
Thank you for your attention

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