Risk assessment, kick modeling mitigate well control risk events in complex operations

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RISK ASSESSMENT AND kick modeling are increasingly used as tools for mitigating well control events in complex and challenging wells.

Risk assessment is a logical and effective process for managing well control risks. It involves identifying and ranking risk events, developing mitigation options to minimize probability and severity of outcome, and providing contingency procedures that can be implemented if the events occur. A case study shows how it helps with decision-making in a difficult drilling project.

Well control modeling makes it possible to investigate otherwise unexpected kick behavior in deepwater, HPHT and other tough drilling situations. It fully simulates transient two-phase flow, and outputs are communicated in simple graphics for easy application in the field. It is a practical tool for well planning and drilling operations. A case study is presented from the dozens of wells that have been modeled.

ROLE OF RISK ASSESSMENT

Occurrence of well control events is an ever-present risk in oil and gas exploration and production operations. In many cases, it is not possible to completely eliminate these risks, so they must be managed to an acceptable level in terms of safety, environmental impact and financial losses. Accidents, near-misses and other unexpected events often result from risks that have not been managed. Risks of all kinds are inherent in the hydrocarbon extraction business, and management is expected by owners and other stake-holders to be diligent in making decisions regarding the risks. Risk Assessment (RA) is a process that can be used to develop information to help with making such decisions involving well control.

The RA process: While generic RA is used by many organizations as a tool for managing risks, the discussion here will focus on its application to well control.

Basically, the RA process involves identifying and ranking risk events, developing mitigation options to minimize probability and severity of outcome, and providing contingency procedures that can be implemented if the events occur. The risk events are then re-ranked assuming that mitigations and contingencies (M&C) have been applied, which will show whether the M&C have changed these risks to an acceptable level.

Operational tasks for Option I: Re-enter and drill to target depth
1. Remove corrosion cap
2. Run BOP and riser, test same
3. RIH with 17 ½ in. bit to 430m
4. Displace hole and riser with 1.55 mud
5. Drill plug #4
6. RIH to 1,568m
7. Displace hole with 1.55 mud
8. Pressure test plug #3 and liner lap
9. Drill plug #3
10. Open hole LOT to 1.68 max EMW
11. Drill plug #2
12. RIH to 2,348m
13. Open hole LOT to tol.68 max EMW
14. Drill plug #1
15. Circulate and condition hole at 2,603m
16. POH
17. Runs 13⅜ in x 11 ¾ in casing
18. Cement 13⅜ in x 11 ¾ in casing
19. Resume planned program and drill to TD

Figure 1 (above): Using the risk assessment process in the case history project, three options for re-entering a well were reviewed. Possible well control events were ID'd using the proposed drilling procedures to provide focus on each phase, such as shown for Option I. Figure 2 below shows the ranking matrix used to rank risk events based on probability and severity of outcome.

Severity of outcome				Probability			
General terms	Financial or assets	Pollutant release	Well control	Very Unlikely 1	Unlikely 2	Likely 3	Very Likely 4
A Avoid at all costs	> $3,000k	Uncontained	Blowout needing relief well	M	H	H	H
B Definitely no	< $3,000k	Contained, < 1000 bbl equiv.	UGBO or blowout, relief well not needed	M	M	H	H
C Not desirable	< $1,000k	Contained, < 100 bbl equiv.	Well kick requires SI & circulate	L	M	M	H
D Part of the business	< $300k	Contained, < 10 bbl equiv.	Circulate and/or raise MW	L	L	L	M

Case history in RA: This project involves the planned re-entry of an offshore well that was drilled from a semi-submersible and had been temporarily abandoned (TA) due to pressure control problems before reaching its objective. The open hole was sealed with cement plugs in its upper portion and across the casing shoe. Apparently no cement plugs were spotted against the several gas sand intervals to isolate them, and there was concern that the overpressured sands might have charged up lower pressure zones, or the open hole wellbore, or both. Upon re-entry, exposure to such charged pressure may break down the formation at the casing shoe, thus causing an underground cross flow.

Options to be evaluated: The operator's objective was to evaluate relative well control risks for these options:

I. Re-enter and drill to target depth: Up side for this option is the low cost involved if the scenario of charged pressures does not occur. Down side is charged up pressure and possible underground cross flow, and the high cost to abandon operations under these conditions.

II. Sidetrack from a window in the 16-in. casing and drill to target depth: Up side for this option is that, even if the zones are charged up, they will be penetrated one at a time and therefore provide the opportunity to abandon operations more easily. The down side is the longer time and rig cost required.

III. Leave the well in its current condition as permanently abandoned: Up side is there is no cost involved. Down side is the possibility that the wellbore pressure may eventually build up and broach to the sea floor.

An RA work session was conducted with participation by key individuals involved in the project. The three options were reviewed to identify possible well control risk events, using the proposed drilling procedures to provide focus on each phase, such as shown in Figure 1 for Option I. Risk events were ranked using the ranking matrix in Figure 2, where each risk event is ranked based on probability and the highest severity of outcome from the four categories of personnel safety, pollution release, well control and financial or asset loss.

Figure 3 is a partial example of the tabulated results, including M&C and re-rank. Two of the high-ranked risk events for Option I are shown in this table, which involve encountering high-pressure gas and/or underground flow in progress below the capping cement plugs. There are few realistic mitigation options for these events other than being prepared to implement available contingency measures accordingly. Consequently, these risks remain at a high level when re-ranked with M&C in place.

Result: A summary of re-ranked risk profile for the options is shown in Figure 4. Due to the relatively larger number of high risks, a decision was made against Option I. Option III was also ruled out because it would have yielded no exploratory information, even though the option involved little well control risk. Final decision was to proceed with Option II.

WELL CONTROL MODELING

Well control modeling makes it possible to investigate otherwise unexpected kick behavior in deepwater, HPHT and other tough drilling situations. It fully simulates transient two-phase flow, and outputs are communicated in simple graphics for easy application in the field. It is a practical tool for well planning and for drilling operations. A case study is presented from the dozens of wells that have been modeled.

The software used for this work is the "kick" simulator developed by Norway's Rogaland Research Institute and marketed by **Scandpower**. It simulates a kick from time of influx, through flow

Operations: **Drill Plug #3**				
• Persistent gas below plug #3 or plug #2 not found	H-2A	• Be prepared to execute any and all contigency options	• Shut well in, circulate out gas through separator, keep gas out of riser. • May need multiple attempts to set barite plug and shut off source of gas. • Disconnect riser if gas proves to be unmanageable.	H-2A
• Mud flowback from previous losses	M-2C	• Be prepared to execute any and all contigency options	• Observe well and/or shut in to determine if flow is gas kick or mud flowback. Circulate out gas or bleed off mud flow according to pressure behavior of well.	M-2C
Operations: **1. Open hole LOT to 1.68 max EMW** **2. Drill plug #2** **3. RIH to 2,348m**				
• Underground blowout below plug #2, resulting in severe losses and unstable well behavior	H-2A	• Be prepared to execute any and all contigency options	• Attempt to drill / RIH to TD, stop flow and cure losses with LCM pill, barite plug. • Run noise / temperature / neutron logs to determine flow path.	H-2A

Figure 3 shows partial results of the risk assessment process, including two high-ranked risk events for Option I . Option I was eventually ruled out due to the relatively large number of high risks.

check, shut-in and subsequent kill operations. Since it is a transient simulator, it allows changes in operating conditions to be made at any point during the well control process. Besides standard kill methods, it can also model the full effects of special procedures such as extended shut-in of a kick, changing mud weight or pump rate during a kill, and lost circulation. Following are some ways it can be used to provide well control engineering for planning and operation of a drilling project:

Kick tolerance evaluation for well planning: These simulations generate circulating kick tolerances based on circulating out, not just shut-in, of well kicks over a range of magnitudes and sizes. The overall wellbore design, including casing shoe fracture pressure and surface gas handling equipment, are evaluated for their limits. Data from these simulations can also be used to evaluate casing design, as well as surface well control equipment. This analysis is done for each critical section of the hole.

Figure 5 shows a typical graphical summary presentation of circulating kick tolerance, which can serve as a useful guide for drilling operations. Figure 6 is a more detailed view of one of the kick tolerance plots, and Figure 7 shows a typical graphical output from the simulations.

Option	Low-level risks	Medium-level risks	High-level risks	Total
I	8	6	6	20
II	3	5	1	9
III	4	0	0	4

Figure 4 shows a summary of the re-ranked risk profile for the three options. Option I had a relatively larger number of high risks. Option III was ruled out because it would have yielded no exploratory information, even though little well control risk was involved. Final decision was to proceed with Option II.

Kick circulation modeling for drilling operations: Each set of circulating kick tolerance chart is for a specific combination of fracture gradient at the casing shoe, mud weight range, casing setting depth and hole depth. They can be updated on a regular basis as changes occur while drilling a well. Examples of such changes that alter kick tolerances are increases in mud weight, unexpected results in shoe tests, unexpected pore pressures, change in casing points or setting a contingency liner, or an extension in target depth of the well. The high speed of these simulations means changes and updates can be made in a matter of minutes, thus allowing results to be communicated on the Internet close to real time.

Well control operations: These simulations are used to support real-time well control operations, including multiple runs to evaluate kick-handling options. Results have closely matched actual field measurements. The versatility of this simulator allows the modeling and evaluation of different well control procedures besides standard kill methods. These include changing mud weight, pump rate and other conditions during a kill, changing choke, line and gas separator sizes, extended shut-in before or during a kill, volumetric kill, and losing returns during a kill.

Case history in well control modeling: A well took an 80-bbl kick while drilling at 27,000 ft with synthetic-based mud (SBM). The well was being drilled in 7,000-ft water depth from a semisubmersible. Following is a description of the sequence of events:

- The well was shut in, and a simulation run was made to model the circulation of this kick using Driller's Method.

- Operator's initial decision was to bullhead the kick back into the formation. The reasoning was that, with an initial shut-in casing pressure (ISICP) of 1,800 psi (point A in Figure 7) and an assumed gas kick, maximum choke pressure was expected to be several times that value when gas reaches surface.

- The simulation showed that, with ISICP at 1,800 psi, wellbore pressure at the casing shoe had almost reached formation fracture pressure (point B).

- Bullheading would have resulted in breakdown of the formation and pumping mud away at the shoe. Additional influx would then enter the wellbore, likely causing an underground flow from the kick zone to the shoe.

• The simulation also showed that, if the kick is circulated out properly using Driller's Method, maximum choke pressure when gas reaches surface (Point C) would be practically the same as ISICP. An explanation for this pressure behavior is that a gas kick often goes into solution in SBM. It actually is part of the liquid phase, and therefore there is no free gas expansion to cause a rise in choke pressure.

• Based on above information from the model, a decision was made to circulate out the kick using Driller's Method. Pressures and volumes recorded on the rig during this circulation closely matched the values predicted by the model.

• Well control experience for many drilling professionals are limited to shallower wells and/or water-based mud (WBM) systems, where choke pressure does become much higher than ISICP when gas reaches surface.

• Applying the same expectation to synthetic- or oil-based systems can lead to misleading results as seen above. Running the simulations in this case likely helped the operator avoid an expensive remedial well control operation.

The above pressure behavior applies only if the kick is small enough for the gas to be completely dissolved without saturating the SBM. Beyond this point, free gas will be present, and pressure behavior will be quite different. In an actual kick, it is always advisable to run simulations to model the scenario and provide information to support well kill operations.

CONCLUSION

Well Control Risk Assessment and Kick Modeling are useful tools for mitigating risk events for complex and challenging wells. This risk assessment process has been effective in providing information for management decisions in many drilling and well-related projects. Kick modeling has been used successfully as a tool for well planning and drilling operations for more than 100 wells. It has also been applied many times to provide real-time information to support well kill operations, and results have closely matched with field data.

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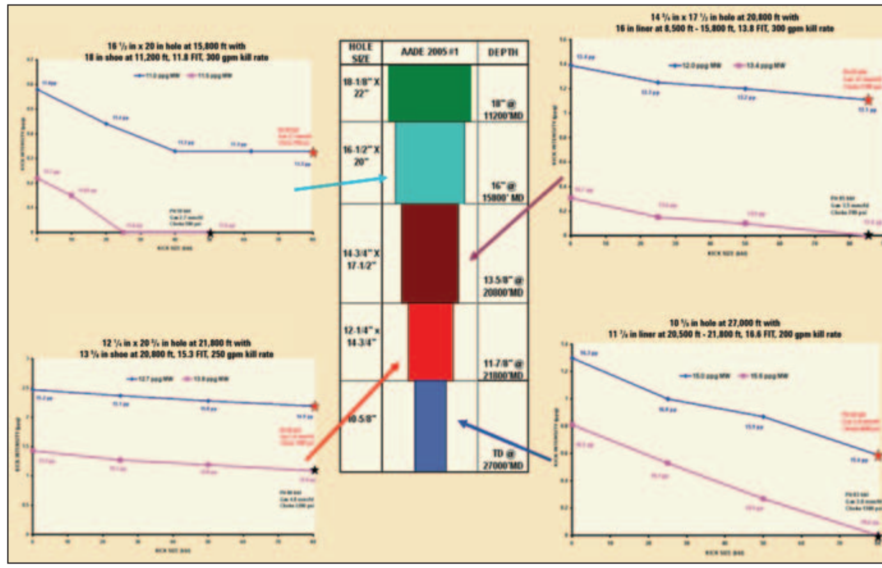

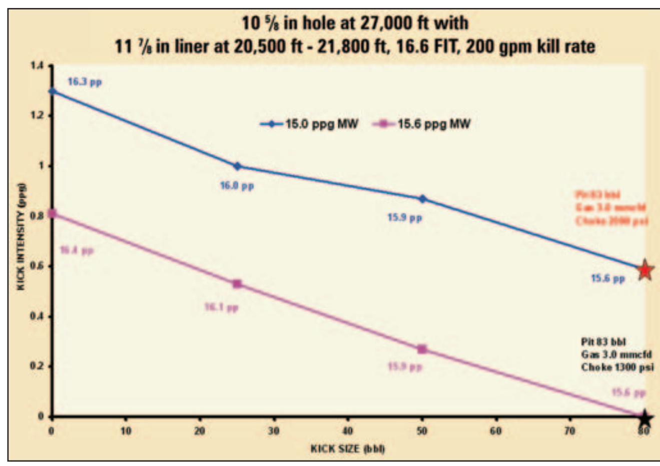

Figure 5 (above) shows a typical graphical summary presentation of circulating kick tolerance, which can serve as a useful guide for drilling operations. Figure 6 (left) is a more detailed view of one of the kick tolerance plots.

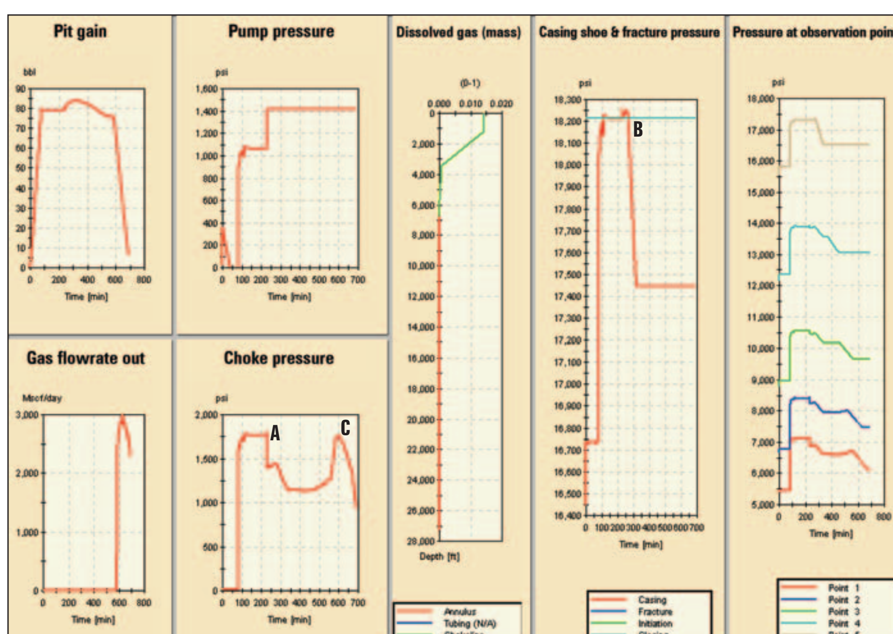

Figure 7 shows a typical graphical output from the well control modeling simulations, which can help to investigate otherwise unexpected kick behavior.

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